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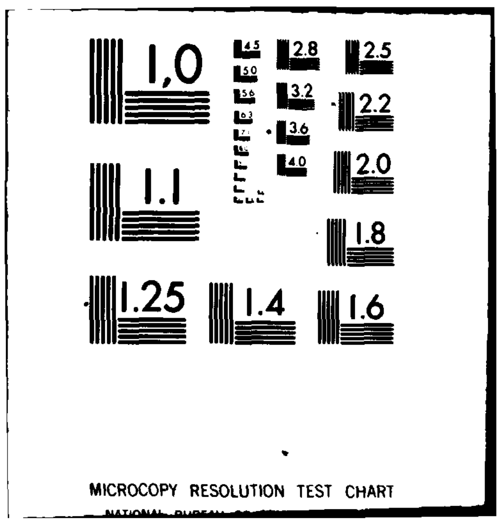
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USE OF ELECTROMYOGRAM INFORMATION TO
IMPROVE HUMAN OPERATOR PERFORMANCE

THESIS

AFIT/GSM/SM/79D-18

Mark C. Kipperman
Capt USAF

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USE OF ELECTROMYOGRAM INFORMATION TO IMPROVE HUMAN OPERATOR PERFORMANCE

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

Mark C. Kipperman
Captain USAF

Graduate Systems Management

December 1979

Approved for public release; distribution unlimited.

Preface

When Dr. Saul Young mentioned a possible thesis project involving biofeedback, the idea intrigued me. Although I had no personal experience with biofeedback, I had done some reading on the subject and thought that it would be a fascinating field of study. As it turned out, the process of experimentation and analysis, not just the biofeedback, was interesting and enlightening to me. I feel as if I have truly been immersed in the problems of experimental design, execution, and analysis.

This project involved a great deal of time and effort on the part of many people, and I would like to express my thanks to them. Andrew Junker and Saul Young developed the initial experimental protocol and gave invaluable advice and assistance along the way. Dr. Lynn Wolaver provided the biofeedback equipment. Grant McMillan, Marvin Roark, Warren Miller and Jim Ater at AMRL were very helpful in providing facilities and equipment with which to conduct the tracking experiments. Of course, my thanks also go to the experimental subjects, who volunteered so much of their time. They are:

Bart Boggs	Bob McIntyre	Tom Scanlan
Joe Cafarella	Grant McMillan	Dave Smedley
Dennis Dailey	Rich McNally	Bob Taylor
Bill Frazier	Dick Mosbach	Tom Wade
Gil Fried	Bill Nusz	Norbert Wagner
Mike Gusmus	Jim Rechtorovic	Bill Wise
Duane Johnson	Art Ross	

Finally I would like to thank my wife, Molly, for taking care of so many problems that I neglected while working on this thesis.

Mark C. Kipperman

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Abstract

This research was conducted to investigate the effects of electromyogram (EMG) biofeedback on learning and performance of a compensatory hand-eye tracking task. A total of twenty male subjects took part in the experiments, with each participating in at least 48 scored tracking runs on the Roll Axis Tracking Simulator.

The subjects were divided into three groups. The control group received no biofeedback, the first experimental group received biofeedback relaxation training and biofeedback while tracking, and the second experimental group received biofeedback relaxation training only. Comparisons across the three groups showed significant differences in muscle tension levels, but no significant differences in performing the tracking task.

Analysis of scores from each subject showed learning to have the most significant relationship to score, and demonstrated the log/log nature of the learning curve. When averages were taken across all subjects, 98 percent of the variance in logarithm of score was accounted for by the relationship with logarithm of run number.

USE OF ELECTROMYOGRAM INFORMATION TO IMPROVE HUMAN OPERATOR PERFORMANCE

I Introduction

The Air Force is always looking for ways to improve operational mission effectiveness, and the ability of pilots to perform their tasks is an important factor in the overall performance of the Air Force. No field of knowledge that could lead to improved pilot performance should be ignored.

In the last several years great advances have been made in aircraft instrumentation and avionics. The pilot of a modern aircraft can identify its location, altitude, speed, and direction, all in a very short time. The condition of the aircraft itself is also monitored in detail, with some systems even including automatic troubleshooting diagnostic routines. The one part of the weapons system that is not monitored is the pilot himself.

Techniques for monitoring automatic body functions and for learning voluntary control over them have existed for many years, but only recently have they been combined and scientifically studied. A new field of study called biofeedback has developed, concerned with "feeding back" physiological information to an individual to enable selfmonitoring and control of physiological processes (Brown, 1977:3). If biofeedback can improve pilot performance, it has tremendous potential for the Air Force.

Background

Concept. The original concept for this project came from two men at Wright-Patterson Air Force Base: LtCol George C. Young, Jr., a professor at Air Force Institute of Technology, and Mr. Andrew Junker, an engineer at Aerospace Medical Research Laboratory (AMRL). Young had been involved with clinical applications of biofeedback, and Junker had helped design a target-tracking simulator at AMRL. Their idea was to investigate the use of biofeedback during the tracking task to determine whether the biofeedback information could improve performance.

Literature Review. In her book New Mind, New Body, Barbara Brown presents a detailed explanation of the field of biofeedback and its historical development. She explains that biological feedback systems within the body have been known for some time, but the breakthrough in biofeedback came with the introduction of an external portion of the feedback loop. Brown explains,

> The real biological feedback drama unfolded when it was discovered that we could tap the hidden secrets of the completely internal, life-governing functions of the body, that we could capture the internal signals and transform them into externalized, information-bearing signals

> that could be sensed, perceived, recognized, and acted upon by our brain's control system (Brown, 1974:5).

One of the externalized signals to which Brown refers is the electromyogram (EMG), a measure of muscle tension level. Physiologist Edmund Jacobson pointed out the existence of residual tension, that tension a person maintains even when apparently at complete rest. Jacobson noted that residual tension can be measured by measuring the amount of muscle electrical activity (Brown, 1974:141). That measurement is accomplished by the EMG.

Robert Benshoff's report on self-regulation is much more cautious about the applications of biofeedback than is Brown's book. Benshoff points to several research efforts that found little promise in the use of biofeedback for improved performance. Stoyva and Budzynski, for example, compared subjects with and without muscle relaxation training at six different tasks, and found no significant difference between the two groups (Benshoff, 1976:15-18).

Benshoff sums up his position by saying, "Until further research establishes a discrete relationship between specific physiological events and performance, or until new techniques for biofeedback become more efficient, further efforts toward the utilization of self-regulation to performance enhancement do not appear reasonable (Benshoff, 1976:2)." It was decided to proceed with the project despite Benshoff's caution, modifying it to include more emphasis on learning, EMG measurement, and the search for a relationship between tension level and performance.

Statement of the Problem

The EMG provides information which may be of value in improving human operator performance. This information is not currently being used in US Air Force aircraft because the value of EMG information in this area has not been demonstrated.

Objectives

Primary Objectives. Investigate possible advantages of employing electromyogram information during learning of a hand-eye tracking task.

Investigate possible advantages of employing EMG information during performance of a previously learned hand-eye tracking task.

Secondary Objectives. Investigate the relationship of EMG tension levels and performance of a hand-eye tracking task.

Increase understanding of learning curves and the nature of the learning process.

Personal Objectives. Become familiar with some practical research methods.

Develop a detailed understanding of statistical analysis techniques.

Scope, Limitations, and Assumptions

Scope. This thesis is restricted to the study of a single physical task: pitch tracking on the Roll Axis Tracking Simulator (RATS) at the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio. Conclusions drawn from this study would not necessarily apply to other tasks.

The tracking task consisted of attempting to keep a target image in the center of a television screen by applying pressure on a control stick. The target would move vertically based on computer-generated disturbance signals and control stick inputs. Each tracking run was scored for 180 seconds.

There were twenty subjects in the study, with each one accomplishing 48 tracking runs. Thirteen subjects received biofeedback relaxation training, with seven also receiving active EMG feedback during their scoring runs, and five received no relaxation training at all. The other two subjects, both considered to be expert trackers, received relaxation training followed by active biofeedback on half their runs.

Four subjects continued past 48 scoring runs, receiving active biofeedback on half of their subsequent runs.

Limitations. Scheduling limitations and computer availability restricted the number of subjects to twenty.

This small number of subjects makes it more difficult to identify significant differences between groups.

Biofeedback relaxation training consisted of one 30-45 minute session per subject. This training was reinforced with 5-10 minutes of biofeedback prior to each tracking session. It could be argued that more intensive biofeedback training, such as one hour a day for two weeks, might lead to different experimental results.

Assumptions. The 18 subjects were assumed to be randomly selected into their three groups, with the exception of attributes specifically identified in the linear regression model. Each subject was assumed to be tracking to the best of his ability during each tracking run.

Organization

This thesis is divided into five chapters. Chapter I introduces the topic and provides background information. Chapter II describes the equipment used in the experiments. Chapter III discusses the experimental design and the methods used to gather, treat, and present the data. Chapter IV is an analysis and discussion of experimental results, and Chapter V presents a summary, conclusions, and recommendations. Appendices provide the experimental data and some computer analyses of results.

II Experimental Equipment

Two separate sets of equipment were used in these experiments. A tracking simulator was used to generate the tracking task and compute error scores, and biofeedback equipment was used to compute muscle activity levels and to provide audio biofeedback.

Biofeedback Equipment

Electromyogram (P303, Cyborg Corporation, 1977). The Cyborg P303 Clinical EMG was used to provide audio signals to those subjects receiving biofeedback and to measure muscle activity for all subjects. The subjects would hear a repetitive tone in their earphones. The pitch and repetition rate of the tone would increase with increasing EMG activity, with pitch variation possible from 100 Hz to 1000 Hz. Figure 1 is a diagram of the EMG controls.

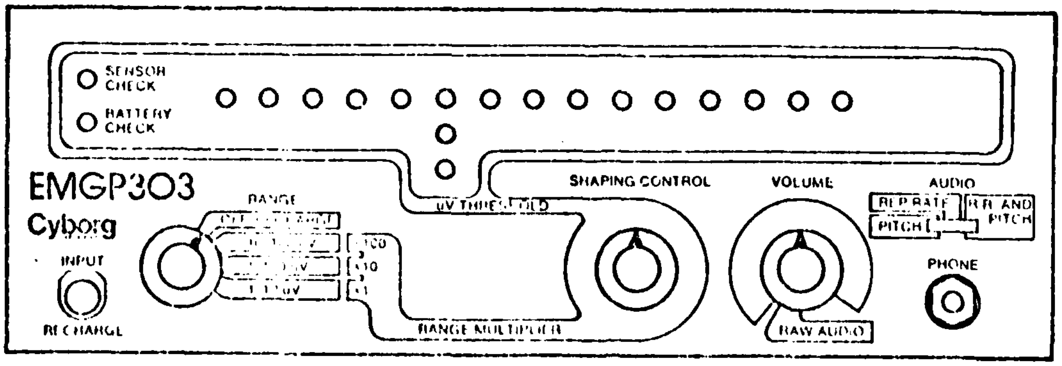

Fig 1. Cyborg P303 Clinical EMG (P303, Cyborg Corporation, 1977)

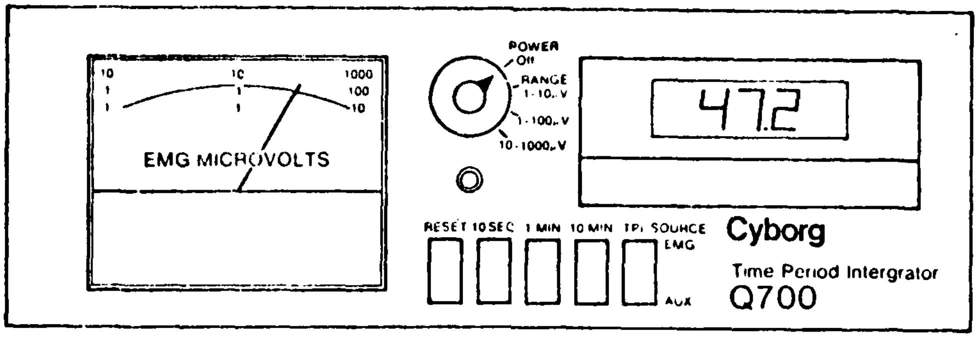

Fig 2. Cyborg Q700 RMS Data Accumulator
(Q700, Cyborg Corporation, undated)

Threshold level and range multiplier could be adjusted to allow for individual differences in tension level. Ranges available were 0.1-10 microvolts, 1-100 microvolts, and 10-1000 microvolts. Threshold level, the lowest level at which audio feedback is generated, could be selected within each range. Volume of audio feedback was also adjustable.

Data Accumulator (Q700, Cyborg Corporation, undated). The Cyborg Q700 RMS Data Accumulator was used to transform the continuous EMG readings into averages that could be used in data analysis. The Q700 used Time Period Integration, the averaging of a signal over a period of time. A reset button was pressed to start the averaging process, and EMG data was averaged for a preset time period. At the end of the time period the average EMG level was displayed on light-emitting diodes, and averaging automatically began for the next time period. Figure 2 shows the front panel of the Data Accumulator.

Time periods available on the Q700 were ten seconds, one minute, and ten minutes. During tracking runs, readings were taken at one-minute intervals for three minutes.

Roll Axis Tracking Simulator

All tracking runs were performed and scored on the Roll Axis Tracking Simulator (RATS) at Aerospace Medical Research Laboratory, Wright-Patterson AFB. Although the simulator was capable of motion and disturbance in the roll axis, the preliminary benchmark experiments employed in this study used only pitch tracking with no motion.

Hardware. The simulator was a basic cockpit design with a pilot's seat and a control stick. The stick was a forward-back force control stick located approximately 30 cm to the right and 25 cm in front of the subject; an arm rest was located at a comfortable height to provide support for the subject's arm. The stick was approximately 14 cm high, and the subjects could use a combination of finger and thumb grips or their entire hand to manipulate it.

An 8-inch-diagonal television screen was used for the tracking display. The display was centered in azimuth approximately 70 cm from the subject's eyes, and within ten degrees of each subject's eye level.

Computers used to generate signals, integrate stick inputs, and provide scores were a Digital Equipment Corporation PDP 11/40 digital computer and an Electronics

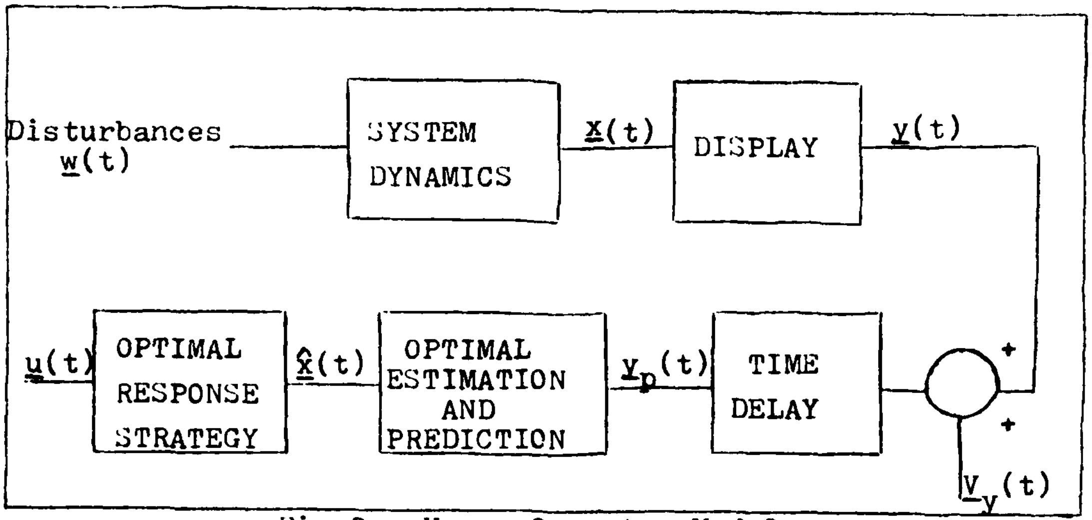

Fig 3. Human Operator Model.
(Zacharias and Levison, 1978:38)

Associates Incorporated 580 analog computer. The digital computer drove an X-Y oscilloscope, and a camera was used to convert the image on the oscilloscope to a video signal, which was transmitted by coaxial cable to the television screen in the simulator (Roark, 1979).

Software. The tracking task was an adaptation of a compensatory tracking task design by Bolt Beranek and Newman Incorporated (Roark, 1979). The design began with a human operator model, and added system dynamics to form a model of the overall tracking task.

The human operator model for processing continuous information is shown in Figure 3. System dynamics are described by x(t), the vector which describes the state of the system, and w(t), a noise or disturbance vector. Display, y(t), is a function of the state of the system, and

$\underline{v}_y(t)$ represents observation noise, the difference between the actual display and the perceived display. After a perceptual time delay, the operator reacts to the perceived display $\underline{y}_p(t)$ by estimating the state of the system $\hat{\underline{x}}(t)$ and formulating a response activity $\underline{u}(t)$. In the case of a closed-loop continuous control system, the response activity is a control input to the system (Zacharias and Levison, 1978:5-6).

Using the human operator model just described, the tracking task was designed to meet two specific objectives:

> a. Overall sensitivity of the task to changes in operator behavior induced by environmental stressors, and
> b. Differential sensitivity of the task to qualitatively different stressors (Zacharias and Levison, 1978:5).

The objectives were chosen to enable measurement and identification of changes in performance due to slight changes in task environment.

One of the most basic determinants of performance is the set of dynamics used in the tracking task. If the dynamics are easy to control, tracking performance tends to be insensitive to environmental changes; if they are difficult to control, performance level can be highly sensitive to the same changes (Zacharias and Levison, 1978:16).

The RATS used unstable dynamics with a fixed instability, together with a loop input disturbance signal.

The general form of plant dynamics P(s) is given by the following Laplace transform with transformation variable s:

$$P(s) = \frac{L}{s-L}$$

The plant pole location L was equal to 2.0 radians per second. Score sensitivity tests conducted by Bolt Beranek and Newman showed this value to be a good compromise between insensitivity (L=1.0) and loss of control (L=4.0) (Zacharias and Levison, 1978:26).

The purpose of the loop input disturbance signal is to continuously move the target and necessitate continuous compensatory control actions by the human operator. It is important that the disturbance signal appear to the operator to be random; otherwise, the operator may begin to perceive a pattern and anticipate disturbances instead of reacting to them (Zacharias and Levison, 1978:21).

High-frequency disturbance signals can present extremely difficult tracking problems, but those signals can be attenuated in power through the use of a power spectral density (PSD) function. To combine high-frequency attenuation with random-appearing signals, the RATS input disturbance signal was constructed from 13 sinusoids whose PSD approximated the following continuous PSD function:

$$\phi_{dd}(w) = \frac{2a}{w^2 + a^2}$$

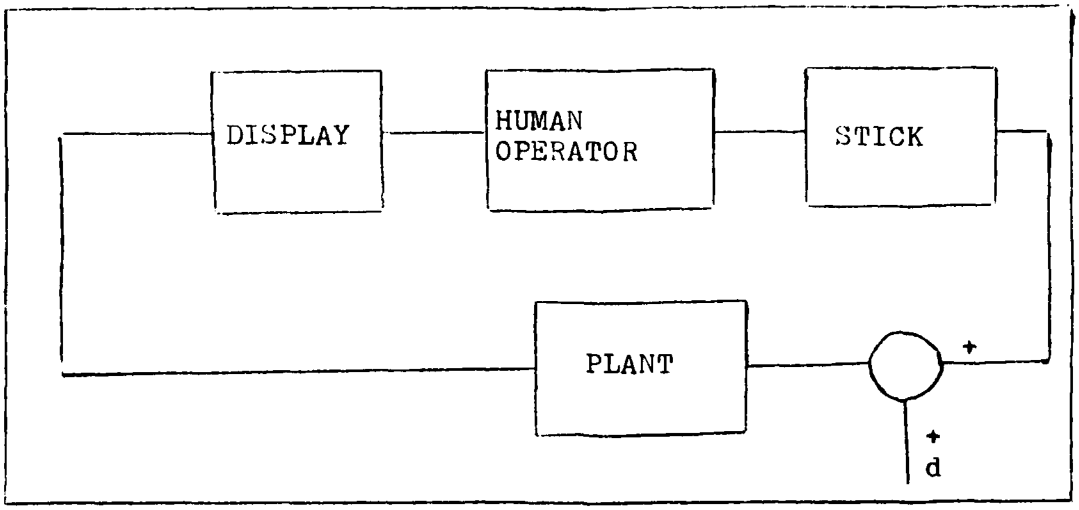

Fig 4. Tracking Task Block Diagram
(Zacharias and Levison, 1978:38)

where "w" equals 25 Hertz and "a" equals 0.5 radians per second (Zacharias and Levison, 1978:21,39).

Figure 4 is a block diagram of the tracking task. The RATS differs from the original model in that stick gain is incorporated into the plant dynamics and the disturbance signal is generated in the digital computer rather than the analog computer (Roark, 1979).

The specific plant dynamics used in these experiments were as follows:

$$P(s) = \frac{K\,L}{s - L}\, e^{-t_o s}$$

The stick gain K was used to convert from pounds of stick force to centimeters of plant command, and was set to 10 cm/pound. Thus, full-scale deflection of the target represented a force of approximately 0.6 pounds. The plant

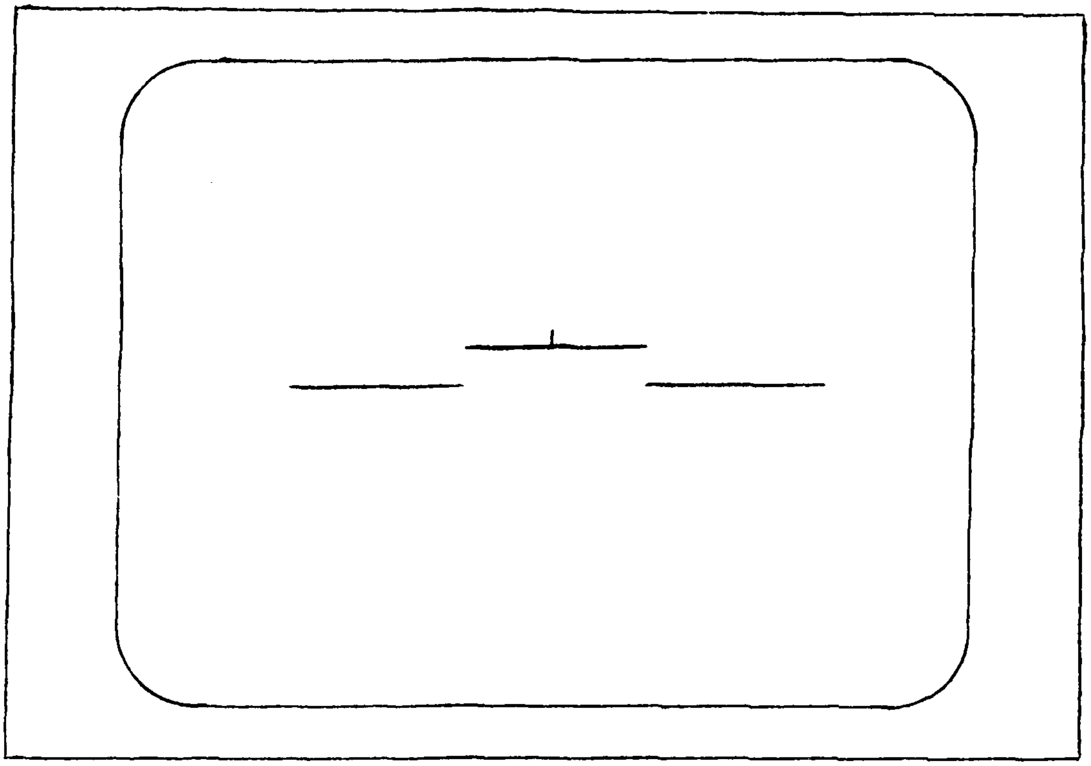

Fig 5. Typical Tracking Display (3/4 actual size)

dead-time (time delay) t_o, a processing and interface delay inherent in the simulator, was equal to 65 milliseconds (Roark, 1979).

A typical tracking display is shown in Figure 5. The display consisted of three horizontal lines, each 3.3 cm long. The two outer lines were centered vertically on the television screen, while the third line (the target) could move up and down between them. The target was also differentiated by a small vertical pip in its center.

Error scores were based on mean square displacement from the center of the screen, with samples taken 25 times per second for the duration of the scored run. Displacement was measured in raster grid units, with one unit equal to 0.02 cm. Thus, an average (weighted) displacement of 1.0 cm would produce a score of 50^2, or 2500; an average (weighted) displacement of 0.4 cm would produce a score of 20^2, or 400. Scores were displayed on the television screen after the conclusion of each run.

III Experimental Procedures

Data Gathering

Questionnaires. Each experimental subject filled out a short questionnaire prior to beginning the experiments. Questionnaire information was used to identify demographic variables, such as age and pilot experience, that might affect experimental outcomes. Additional information was gathered to allow for more detailed follow-on analysis and possible use of a tracking simulator with motion. A sample questionnaire is shown in Appendix A.

Twenty male subjects were used for the experiments. The youngest was 18 years of age, and the oldest was 36. Nineteen were right-handed or ambidextrous, and all had vision that was normal or corrected to normal.

Initial Experimental Protocol. The initial experimental design called for the subjects to be divided into two groups, an experimental group and a control group. Both groups would receive initial biofeedback training and reinforcement prior to each scoring session, but only the experimental group would receive active biofeedback; that is, audio biofeedback during the actual tracking runs. Each individual would have seven sessions in the simulator: one for biofeedback training and six for tracking, with eight scored tracking runs in each tracking session.

Biofeedback training and the subsequent use of the EMG were conducted with electrodes on the subject's forehead to measure the electrical activity of the frontalis muscles. In order to avoid confusing generalized tension measurements with active voluntary muscle activity, it was necessary to record activity from some muscle(s) not directly involved in the tracking task; for example, muscle activity in the right arm would not be indicative of general tension level in these experiments (Bolt Beranek and Newman Inc., 1979:29). Precedent for use of the frontalis muscles is found in Stoyva and Budzynski's research on tension headaches. Brown cites several advantages in their selection of the frontalis muscles: high tension levels of the frontalis were associated with tension headaches, relaxation of the muscles is relatively difficult, and biofeedback-associated relaxation effects spread to other muscles of the upper body, such as the shoulders and neck (Brown, 1974:154-155). Cyborg Corporation also recommends use of the frontalis for general relaxation training (P303, Cyborg Corp., 1977).

Each subject received an initial 30-45 minute biofeedback training session. The nature of the experiment and the equipment was described, and electrodes were secured to the subject's forehead with a head strap and electrode paste. The subject was then seated in the simulator, and earphones were put on. The subject was told to try to vary the biofeedback tone by changing the amount of forehead tension, trying to become more aware of what bodily changes accompanied a lowering of tension. EMG threshold levels were adjusted for each individual to insure that changing tension levels produced changing audio tones. Subjects were encouraged to note the effects of the following variables on tension: slackness of jaw, eyes open or closed, hand on or off the control stick, and amount of control stick pressure.

Tracking sessions consisted of five minutes of relaxation with biofeedback, followed by two blocks of four 3-minute scored tracking runs each. Time between runs varied from fifteen seconds to one minute, and time between blocks was approximately five minutes. Tracking sessions were scheduled for one hour, and were normally completed within 45 minutes.

Before each scoring run, the scoring control switch was in the "off" position and the autopilot was on. Immediately before the run, the autopilot would be turned off to activate control stick inputs. When the subject indicated he was ready for the run, scoring was initiated and the Data Accumulator was reset. EMG readings were recorded at one-minute intervals during the run, and tracking error score was recorded from the television screen after the end of the run.

The subjects were given two objectives for the tracking sessions. First, learn to track and minimize tracking error score. Second, if getting biofeedback while tracking, use the biofeedback to relax as much as possible. If not getting active biofeedback, try to relax as much as possible while tracking, using what was learned in previous biofeedback training.

<u>Changes in Experimental Design</u>. Two of the volunteers for the experiments had had a great deal of experience in tracking tasks similar to this one, and were considered tracking experts. It was decided to treat these individuals separately rather than including them in one of the two original groups. Each tracking session for these individuals would consist of four runs with biofeedback and four runs without biofeedback.

Three other subjects volunteered for additional experiments. After their original 48 tracking runs, they continued on to a maximum of 80 runs in all. Half of the extra runs were conducted with biofeedback and half without it. These changes allowed separate analysis with each of these individuals functioning as his own control.

Preliminary analysis of results early in the experimental program revealed no significant differences in performance between the control group and the experimental group. It was decided that merely varying the method of achieving a relaxed state might be too narrow a difference.

The question arose as to whether any conscious relaxation effort would result in improved performance.

To help resolve that question, it was decided to expand the scope of the study by adding a third group of subjects. Electrodes and earphones were used for EMG measurement and standardization of physical conditions, but no audio feedback or biofeedback training was given. These subjects were given only one objective for their six tracking sessions: learn to track and minimize tracking error score.

Data Treatment

Computer Data File. Data from each tracking run was punched onto a computer card in the following format:

Column	Data
1-2	Subject number (01-20)
3	Dominant hand (0=right-handed or ambidextrous; 1=left-handed)
4-5	Age in years
6	Pilot or tracking experience (0=no previous experience; 1=some previous experience)
7	Experimental group (0=received training, but not active biofeedback, 1=received active biofeedback; 2=did not receive biofeedback training)
8-9	Total number of completed runs
10	Number of runs completed in current session
11-14	Tracking error score (to nearest integer)
15-17	Sum of three 1-minute EMG readings (times ten microvolts)

Information for columns three through seven was obtained from completed questionnaires. Individuals who indicated any experience in either piloting or tracking were classified as experienced in column six.

After all cards were punched, the data was catalogued on a computer disk file for ease of handling. The file contained 1,070 cases (cards). All subsequent computer runs, except those involving summary data, used the disk file rather than the punched cards.

Computer Analysis Techniques (Nie et al, 1975). Statistical Package for the Social Sciences (SPSS) program was used for all data analysis. The primary subprogram used was REGRESSION, with both stepwise and forced inclusion. Other subprograms used were CONDESCRIPTIVE, MANOVA, PARTIAL CORR, and SCATTERGRAM.

The cases were analyzed in three different ways: aggregated by individual, aggregated by run number, and individually. Individual cases provided the most data points, of course, but results had to be treated with caution. If a dummy variable for each subject were used, any between-group or demographic effects would be masked. Omitting such dummy variables, however, would lead to highly distorted levels of significance: each scored run would be treated as if it had been accomplished by a different individual.

Cases aggregated by individual provided the truest tests of between-group and demographic differences. Analysis was accomplished twice: once using an overall average score for each individual, and a second time using only runs 25-48, after most of the learning of the task had already occurred.

Cases aggregated by run number could show no individual differences, but they did provide valuable insight into the nature of the learning curve. Using aggregate scores smoothed out much of the fluctuation found in individual learning curves.

The effect of learning had to be considered in the data analysis. E. B. Cochran described characteristics of learning for short cycle operations as follows:

> A close relationship between unit output and unit cost, with the latter shrinking as the former expands in a rather "linear" fashion when plotted on log/log paper, and
>
> An eventual leveling out of cost, as the operator reaches the limits of his capability and ability to find methods improvements (Cochran, 1968:19).

In these experiments, unit output was the number of runs completed and unit cost was the error score. The log/log relationship was accounted for by using natural logarithms of run number and error score as the relevant variables whenever the learning effect was considered. The leveling-out effect could have been accounted for, if necessary, by equating all run numbers beyond the point where all learning had occurred.

Data Presentation and Reporting

Text. The analysis of results is shown in Chapter IV. The chapter is divided into three sections: learning curves, comparison of groups, and within-group and individual results.

Appendices. There are three appendices to this thesis. Appendix A is the questionnaire that was administered to all experimental subjects. Appendix B is a tabular presentation of experimental results, including information from each individual's questionnaire. Appendix C includes a scatter diagram of each individual's learning curve, as well as an aggregate learning curve and an aggregate learning curve adjusted for fatigue.

IV Results and Analysis

This chapter gives the analysis of experimental results, and shows some of the different approaches that were used in analyzing the data. The chapter is in three parts. First, scores are fit to learning curves and the log/log nature of the learning curve is demonstrated; second, results are compared across groups to identify effects of the experimental variables. Finally, within-group and individual results are examined. Individual experimental results are tabulated in Appendix B.

Significance, as used in this chapter, is the probability that the sample population will yield the computed (or higher) coefficient in the regression equation, given that the coefficient for the overall population is zero. A highly significant predictor variable would have a low numerical significance.

Learning Curves

Plots of score against run number for the first four subjects to complete 48 runs (subjects 1, 2, 4, and 5) showed irregular lines convex to the origin of the graph, suggesting an inverse or negative logarithmic relationship between score and run number. When semi-log paper was used, the plots (logarithm of score against run number) still retained a definite convexity, but the use of log/log paper (plotting logarithm of score against logarithm of run number) produced patterns that seemed to be approximately linear. A later search of the literature on learning curves (Cochran, 1968, and others) confirmed the notion of a log/log relationship between performance and experience.

Because of the strong influence of the learning effect, most of the data analysis used the natural logarithm of the score, rather than the score itself, as the criterion variable. Linear regression with such a variable yields predictor variables that have multiplicative effects on predicted score. Since it was felt that some effects may have been additive rather than multiplicative, some analysis with averaged data for each subject used an average raw score as the criterion variable.

Scatter Diagrams. Scatter diagrams were run to produce a visual depiction of each subject's learning experience. Although individual learning patterns and amount of scatter varied a great deal, all curves seemed to generally fit the predicted logarithmic relationship. Percent of variance explained (R^2) varied among individuals from a low of 38.8 percent to a high of 94.2 percent, with mean R^2 equal to 76.9 percent. Scatter diagrams are in Appendix C.

When fluctuations were removed by averaging logarithm of score across all individuals for each run, the predictive power of the learning curve model improved dramatically.

R^2 for average logarithm of score was 97.9 percent. When regression analysis showed fatigue to have a significant effect (significance less than .001) on average performance, a fatigue adjustment was added to the averages. R^2 for the adjusted model increased to 98.5 percent, and the scatter diagram gave convincing support to the applicability of the log/log learning model.

Leveling Off. One other aspect of learning is a leveling-off point, beyond which performance does not improve. Bunching of data caused by the log/log model makes it difficult to identify such a point with much precision, and visual examination of a performance diagram may be the easiest way to locate the approximate leveling-off point. Examination of the adjusted group diagram suggests that leveling off did not occur before the 38th run, and may not have occurred after run number 48. Further analysis of those individuals who went beyond 48 runs revealed no significant additional learning, which suggests that virtually all learning had occurred by the 48th run.

Interruption of Learning. Because of a combination of final examinations, school vacation, and non-availability of the RATS, seven of the subjects had a five-week interruption between tracking sessions. Each of these subjects was given three minutes of refamiliarization time with the control stick before beginning his first session after the interruption. Examination of scores before and after the

TABLE I

Overall Regression on Ln(Score)

Overall F-Value = 225.4		Significance = .000		
VARIABLE	COEFFICIENT	SIGNIFICANCE	R^2	R^2 CHANGE
Ln(Run)	-.537	.000	.393	.393
Expert	-.826	.000	.529	.136
Left-handed	.292	.000	.536	.007
EMG	.747E-2	.000	.539	.002
EMG^2	-.168E-4	.000	.547	.009
Training	.258	.000	.560	.013
Biofeedback	.343	.000	.562	.002
Fatigue	----	.323	----	----
Age	----	.535	----	----
Pilot	----	.656	----	----

interruption revealed no significant shifts in learning curves due to the interruptions.

Comparison of Groups

Initial Analysis. Initial linear regression analysis was performed using each run as a separate case and including EMG and EMG^2 as predictor variables. Although computed significances were unrealistic, the analysis served as a baseline to indicate trends in the data.

There were ten variables considered for inclusion in the regression equation, and seven entered the equation with F-statistics greater than 3.0 (see Table 1). Variables having a positive effect on logarithm of score were left-handedness, EMG, biofeedback, and training. "Biofeedback" refers to the group receiving active biofeedback while tracking; while "training" refers to the group receiving biofeedback training only. Variables with a negative effect were logarithm of run number (learning), tracking expert identifier, and EMG^2. The variables not entering the equation were age, pilot identifier, and fatigue. "Fatigue" was defined for purposes of analysis to be the number of runs since the last rest break.

All three of the omitted variables would seem intuitively to be good predictors. Some explanation of why they were not may help increase understanding of the regression model.

One might expect increased age to have a detrimental effect on performance, but no such effect was observed. Two factors help account for this. First, the sample size of twenty was relatively small. The smaller the sample, the easier it is for a group's performance to not correlate highly with that of the overall population. Second, the age spread of the sample population was small; the youngest subject was 18 years old and the second-youngest was 22, while the oldest was 36 and the second-oldest was 34.

Pilots might be expected to have lower error scores because of better hand-eye coordination and more experience with tasks somewhat similar to the one being measured. Again, two factors help explain why this was not so. First, control stick inputs were, in a sense, opposite to initial pilot expectations; forward pressure drove the target up, and backward pressure drove the target down. Second, and perhaps most important, is the difference between optimal scoring strategy and normal pilot techniques. One subject, a pilot, remarked, "Don't be afraid to overshoot; forget about bringing it back gently to mid-point. Piloting techniques don't work on this task."

Fatigue would be expected to have a detrimental effect on soore. This effect did exist, but was masked in this regression model by the use of EMG and EMG^2 as predictor variables. In the stepwise entry of variables, fatigue had a significance level of .039 before EMG and EMG^2 entered the equation. Later analysis continued to use fatigue as a variable of interest.

Of the variables that entered the regression equation, three can be explained without much further discussion. The first is learning, which was examined in the previous section. Second is the tracking expert identifier, which separates subjects 8 and 11 from the rest of the sample population because of their extensive simulator experience. Although they accomplished half their runs with biofeedback and half without, failure to separate them would bias the results against the control group. The third variable is left-handedness. Since control was exercised with the right hand only subject 3 was left-handed, his scores should not be directly compared with those of the rest of the sample population.

EMG and EMG^2 will be treated together in the discussion. The squared term was included in the analysis to investigate a possible curvilinear relationship between tension and performance; specifically, it had been hypothesized that there was an optimal tension level from which deviation in either direction would degrade performance. The regression model showed both the linear and squared terms to be highly significant (significance .00), but with opposite signs from those hypothesized; the linear term was positive and the squared term negative, producing a maximum positive effect on predicted score at an EMG level of 22.2 microvolts. Fewer than two percent of the runs had EMG levels that high, and increasing tension was generally associated with higher error scores.

One difficulty in using EMG as a predictor variable is that EMG readings were part of the experimental results rather than being previously defined inputs. There is some conceptual difficulty in using EMG readings to predict error scores; higher tension may cause higher scores, but it is also possible that higher scores (that is, target

TABLE II

Regression on Average Ln(Score)

Overall F-Value = .08		Significance = .994		
VARIABLE	COEFFICIENT	SIGNIFICANCE	R^2	R^2 CHANGE
Biofeedback	.177	.642	.016	.016
Pilot	-.102	.742	.018	.003
Age	.858E-2	.790	.025	.007
Left-handed	.118	.858	.027	.002
Training	.883E-1	.814	.032	.005

displacements from center) cause higher tension. The possible feedback effects of tension and target displacement cannot be easily accounted for in the simple linear regression model.

The last two variables in the equation were the group differentiators for the biofeedback group and the biofeedback training group. The final regression equation showed both groups to have a highly significant (significance .000) derogatory effect on score, but significance levels are highly overstated. Each subject produced 48 or more cases for this model, but each case is treated statistically as if it came from a different subject. Even in this distorted model, biofeedback training did not show a significant effect (significance was .115) until after EMG entered the equation.

TABLE III

Regression on Average Ln (Score), Last Half

Overall F-Value = 0.218		Significance = .948		
VARIABLE	COEFFICIENT	SIGNIFICANCE	R^2	R^2 CHANGE
Biofeedback	.270	.474	.074	.074
Pilot	-.623E-1	.838	.077	.003
Age	-.633E-2	.842	.081	.004
Left-handed	.331E-1	.959	.081	.000
Training	.653E-1	.860	.083	.002

Aggregation by Subject. Additional regression analyses were performed with one case per subject. Subjects 8 and 11 were not included, as they could not be identified with a specific experimental group. Only the first 48 runs for each subject were considered. Regression analyses were run using three different aspects of performance as criterion variables: average logarithm of score, average logarithm of score for the last 24 runs (after most learning had occurred), and average raw score for the last 24 runs. Tables 2 through 4 show the results of these regression analyses.

Predictor variables for all three regressions were age, pilot identifier, left-handedness, biofeedback, and training. None of the variables had any significant predictive power (significance less than .200) in any of the

TABLE IV

Regression on Average Score, Last Half

Overall F-Value = 0.131		Significance = .982		
VARIABLE	COEFFICIENT	SIGNIFICANCE	R^2	R^2 CHANGE
Biofeedback	236.0	.492	.038	.038
Pilot	-58.6	.833	.040	.002
Age	-.671	.981	.041	.001
Left-handed	-.681	.909	.043	.002
Training	111.9	.741	.052	.009

three regression equations. These were the most realistic tests of between-group performance differences, and they showed that the differences were not significant.

Another regression analysis was run to compare rates of learning in the three groups. A 48-run learning curve was used for each subject, and the slope (coefficient of logarithm of run number) and Y-intercept (estimated logarithm of score for the first run) became variables in the ensuing regression analysis. Slope times minus one, or rate of learning, became the new criterion variable; Y-intercept, biofeedback, and training were the predictor variables (Table 5).

The regression equation showed biofeedback training (significance .585) to have no significant effect on rate of learning, while biofeedback (significance .035) and

TABLE V

Regression on Rate of Learning

Overall F-Value = 6.20		Significance = .007		
VARIABLE	COEFFICIENT	SIGNIFICANCE	R^2	R^2 CHANGE
Biofeedback	-.161	.035	.390	.390
Y-Intercept	.112	.037	.561	.171
Training	-.374E-1	.585	.571	.010

Y-intercept(significance .037) did have significant effects. Rate of learning was positively correlated with Y-intercept and negatively correlated with the presence of biofeedback. The Y-intercept effect is intuitively appealing; the better the initial performance, the less that remains to be learned. The biofeedback effect may be explained by viewing the biofeedback audio signal as a distraction from the primary tracking task; since tracking receives only divided attention, it is learned more slowly.

The last analysis performed with one case per subject was a regression analysis using EMG as the criterion variable (Table 6). Comparison of groups showed both the biofeedback and biofeedback training groups to have significantly lower readings than the control group (significance less than .010). This was to be expected, since the control group received no specific instructions to relax. In addition there was a slight, but not statistically

TABLE VI

Regression on EMG

Overall F-Value = 7.51		Significance = .006		
VARIABLE	COEFFICIENT	SIGNIFICANCE	R^2	R^2 CHANGE
Biofeedback	-72.1	.002	.192	.192
Training	-61.3	.008	.500	.308
Biofeedback (compared with training)	-10.8	.569	.192	.192
Control Group	61.3	.008	.500	.308

significant, difference between the biofeedback and training groups (significance .569). So it appears active biofeedback aided in relaxation, but was counterproductive in learning the tracking task.

<u>Within-Group and Individual Results</u>

<u>Within-Group Results</u>. This section deals with those subjects who performed tracking runs both with and without active biofeedback, and who could thus serve as their own control group. A big advantage in this method of analysis, especially with small groups, is that all demographic and individual differences are neutralized. A disadvantage that is not directly measurable is that the subjects may unknowingly vary their performances, subconsciously trying

TABLE VII

Regression on Ln(Score) with Internal Control

Overall F-Value = 93.5		Significance = 0		
VARIABLE	COEFFICIENT	SIGNIFICANCE	R^2	R^2 CHANGE
Individuals	----	----	.588	.588
L_n(Run)	-.313	.000	.798	.210
Biofeedback	.454E-1	.155	.798	.001
Fatigue	-.519E-2	.728	.799	.001
EMG^2	-.117E-4	.001	.799	.000
EMG	.727E-2	.001	.810	.011

to help the experimenter. In addition, certain comparisons are not possible, such as between those who have and have not received biofeedback training.

Subjects 3, 4, 7, 8, and 11 all participated in tracking runs with and without biofeedback. For subjects 3, 4, and 7, the first 48 runs were not used in this analysis. After allowing for learning and for individual differences, the effects of biofeedback and EMG on logarithm of score were analyzed, both separately and together (Table 7). Neither variable had any significant predictive power (significance less than .200) in the regression equation.

Individual Results. A regression analysis was performed on logarithm of score with each run as a separate case, but using dummy variables to account for individual

TABLE VIII

Overall Regression on Ln(Score), Allowing for Individual Differences

Overall F-Value = 293		Significance = 0		
Variable	Coefficient	Significance	R^2	R^2 CHANGE
L_n(Run)	-.545	.000	.392	.392
Individuals	----	----	.876	.484
Fatigue	.352E-1	.000	.879	.003
EMG	.895E-3	.509	.879	.000
EMG^2	-.328E-5	.449	.879	.000

subject differences (Table 8). Fatigue entered the regression equation with a significance of .006, but after EMG (significance .000) and EMG^2 (significance .001) entered the equation, the significance of fatigue became .122. The effect of EMG and EMG^2 was to make predicted score a monotonically increasing function of EMG throughout the range of observed EMG values.

Separate regression equations were computed for each of the twenty subjects. Criterion variable was logarithm of score, and predictor variables were logarithm of run number (learning), fatigue, EMG, and EMG^2. Some similarities among subjects were apparent, but the differences that existed showed that not all individuals react the same way to the same experimental variables.

Learning was a highly significant predictor (significance .000) for all subjects. It was felt originally that the two tracking experts might not show any significant learning, but this task was different enough for them that substantial learning did occur.

Fatigue was a significant predictor variable (significance less than .050) for six of the twenty subjects. For one of the six, though, fatigue significantly improved (significance .013) performance instead of degrading it. Perhaps for him, "recent reinforcement of learning" would be a more accurate term than "fatigue".

EMG^2 was a significant predictor variable (significance less than .050) for five of the twenty subjects, accompanied by EMG for two of the five. For two of the subjects, predicted scores rose with EMG throughout its range, and two others had predicted scores rising with EMG through most of its range. Only subject 17 showed a predominantly negative relationship between EMG and predicted score.

It should be noted that neither fatigue nor EMG^2 was a significant predictor variable for a majority of the subjects, although both were significant in aggregate analysis.

V Summary, Conclusions, and Recommendations

Summary

Methods. Experiments consisted of three minutes of target tracking with a force control stick, with each three-minute run scored based on mean squared error. Forehead muscle tension (EMG) readings were taken three times (each 60 seconds) during each tracking run.

There were 20 male subjects, and each tracked for a minimum of 48 runs. The subjects were divided into three groups; the control group received no biofeedback training, the first experimental group received biofeedback training and an active audio biofeedback signal while tracking, and the second experimental group received biofeedback training only. The two experimental groups were told to try to relax while minimizing tracking scores; the control group was told only to try to minimize tracking scores.

Results. The first significant result that was observed was learning. Although individual scores fluctuated a great deal, average performance across all subjects showed an almost steady improvement with experience. The applicability of a log/log improvement model to these experiments was demonstrated, as the log/log relationship between score and run number produced an R^2 of 98 percent.

The main result of analyses using a single representative measure of performance for each subject was that the sample population showed no significant differences between groups and no significant differences caused by demographic factors such as age.

The one area that did produce a significant group difference was rate of learning, or slope of the learning curve. The presence of active biofeedback had a significant detrimental effect on rate of learning, a result that was opposite to the hypothesis being tested.

When each run was considered and individual differences were accounted for, fatigue was shown to be a significant factor in predicting performance. EMG was also a significant predictor, and the addition of EMG to the regression equation caused the removal of fatigue as a significant predictor. This suggests that perhaps fatigue is incorporated into generalized muscle tension.

When separate equations were computed for each subject, individual results varied considerably. Fatigue significantly degraded performance for five subjects, but significantly improved performance for one subject. Similarly, increased tension was significantly associated with degraded performance for four subjects, but was significantly associated with improved performance for one other subject.

Conclusions

In general, biofeedback and biofeedback training did not significantly affect performance in the direction hypothesized. One possible explanation for this is that there were two counteracting effects working simultaneously. First, the biofeedback training and audio signals caused a reduction in tension, which in turn caused an improvement in performance. At the same time, the conscious attempt to relax and the presence of the audio signals were distractions that prevented the subjects' full concentration on the tracking task, thereby degrading performance.

The presumption that biofeedback relaxation training causes a reduction in tension was not directly tested in these experiments, as the control group received no training or instructions concerning relaxation. The difference in tension between the active biofeedback and the biofeedback training groups was not significant for this sample population, although more extensive sampling might show that such a difference does exist.

For the overall population, there was a significant relationship among fatigue, tension, and performance. Regression results suggest that fatigue may not affect performance directly; instead, fatigue causes higher tension, which in turn leads to degraded performance.

The last conclusion is that people are different, which seems to be a basic requirement for understanding human performance. One cannot expect different individuals to react the same way to the same situation, and the realization of that fact must be incorporated in any analysis of experimental results.

Recommendations

Unless other research demonstrates advantageous effects of biofeedback on performance, biofeedback systems should not be included as part of new aircraft design.

It would not appear to be productive to continue these experiments without changes in experimental methodology. Some of the methodology changes that might prove fruitful are as follows:

(1) Raise the EMG threshold for the active biofeedback group so that no audio tone is heard when the subject is relaxed. The audio signal would not be a constant distraction; it would come on only to warn of increased tension.

(2) Include some kind of performance pretest before introducing an experimental variable. This would help account for pre-existing individual differences without the necessity for a large sample population.

(3) Give the control group a relaxation training session without biofeedback, and include relaxation as one of their performance objectives. The biofeedback would then be the only experimental variable, and its effects might be isolated more clearly.

(4) Allow each individual to be his or her own control after learning has occurred, sometimes receiving biofeedback and sometimes not. This would eliminate all the problems of individual differences, (differential reactions, fatigue, etc.), though it might introduce other biases.

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APPENDIX A

QUESTIONNAIRE

Personal Data Information for Tracking Biofeedback Experiments

The following personal information questions are for use by the scientists running the biofeedback tracking experiments in which you are taking part. Be assured that this information will not be divulged to anyone except the project scientists.

Your decision as to whether to supply this information is strictly voluntary. However, without this data we will be unable to properly evaluate your biofeedback EMG and tracking scores. Therefore, we earnestly solicit your help in providing accurate responses to these questions.

Thank you for taking the time to help us in this effort. We sincerely appreciate your interest in our work and your decision to be a volunteer. If you would like a copy of the report resulting from these experiments, please supply your address below:

Name ____________________

1. What is your age (in years)? ____

2. What is your sex?

   a. Male   b. Female

3. How much do you weigh (in pounds)? _____

4. How tall are you? _____

5. What is your highest level of education now?

   a. Non-high school graduate

   b. High school graduate (include GED or equivalency)

   c. Some college

   d. College graduate (BA, BS, or equivalent)

   e. Graduate study but no graduate degree.

   f. Master's degree

   g. Doctor's degree (PhD, MD, LLB, EdD, etc.)

6. What is your marital status?

   a. Married   c. Divorced, not remarried
   b. Single, never married   d. Legally separated
   e. Widow/Widower

7. Which of the following best describes you?

   a. Right-handed   b. Left-handed   c. Ambidextrous

8. Would you consider yourself unusually susceptible to motion sickness? (For example, do you get "car sick" easily, or get motion sick on carnival rides?)

   a. Yes   b. No

9. Do you have a history of double vision, eye surgery, best corrected vision less than 20/20, abnormal depth perception, or decreased visual field?

   a. Yes   b. No

10. Have you ever had any of the following diseases? (Circle yes answers)

a. Diabetes

b. Multiple Sclerosis, seizure disorder, other chronic neurological disease, or an abnormal brain wave test.

c. Head injury resulting in disturbance of consciousness.

d. Fainting spells or low blood pressure.

e. Psychiatric disorder.

f. Any heart disorder, abnormal electrocardiogram, or decrease in exercise tolerance.

g. Alcoholism

h. Blood in your stools or ulcerative colitis

i. Blood in your urine or kidney disease.

j. Chronic liver or lung disease.

k. High blood pressure.

l. Inner ear problems.

11. Are you currently taking any drugs or medication? (Other than vitamins or birth control pills.)

a. Yes b. No

12. Have you taken any drugs or medication (legal or otherwise) in the past two months? (Other than vitamins, birth control pills, or over-the-counter pain relievers.)

a. Yes b. No

If yes, please describe briefly:

13. Do you have full use and range of motion of all extremities and spine?

a. Yes b. No

14. Do you have, or have you had, any other medical condition(s) of which you feel the investigator should be aware?

a. Yes b. No

If answered yes to question 14, please describe briefly:

15. What is your flying status?

a. Rated pilot

b. Not a rated pilot, but holding a private pilot's license.

c. Some piloting experience, but not a pilot.

d. No piloting experience.

16. Do you have any previous target-tracking experience? (Air-to-air combat, gunship sensor operator, etc.)

a. Yes b. No

If yes, please describe briefly:

17. Do you have any previous experience with biofeedback or the EMG (electromyogram)?

a. Both biofeedback and EMG.

b. Biofeedback, but not EMG.

c. EMG, but not biofeedback.

d. None

APPENDIX B

INDIVIDUAL EXPERIMENTAL RESULTS

SUBJECT 01	Run Number	Error score	EMG total(x10)
	1	7037	50
Ambidexterous	2	5291	55
	3	3478	54
18 years old	4	4014	66
	5	2065	52
No pilot experience	6	1695	60
	7	3112	58
	8	3111	50
Active biofeedback	9	2850	48
	10	3636	51
	11	3235	55
	12	2339	52
	13	3070	37
	14	3010	51
	15	2158	52
	16	2420	55
	17	1223	48
	18	2506	51
	19	1622	50
	20	1725	50
	21	1848	46
	22	1047	51
	23	1191	52
	24	1207	58
	25	2185	59
	26	1390	60
	27	1326	62
	28	1677	63
	29	1093	53
	30	825	53
	31	1225	49
	32	1375	69
	33	808	46
	34	1171	48
	35	849	43
	36	860	46
	37	1391	42
	38	637	40
	39	1118	49
	40	948	39
	41	907	52
	42	1060	60
	43	1771	77
	44	1663	70
	45	1059	56
	46	1318	56
	47	1977	80
	48	1056	44

TABLE IX. EXPERIMENTAL RESULTS, SUBJECT 1

SUBJECT 02	Run Number	Error Score	EMG total(x10)
	1	4676	35
Right-handed	2	3356	43
	3	3180	65
33 years old	4	3328	70
	5	3507	38
No pilot experience	6	3405	57
	7	1133	56
	8	1703	59
Biofeedback training only	9	1939	58
	10	1674	51
	11	1202	36
	12	1624	55
	13	1078	65
	14	1395	65
	15	1258	35
	16	959	49
	17	787	60
	18	947	62
	19	979	34
	20	956	58
	21	1198	71
	22	939	66
	23	687	47
	24	750	53
	25	745	59
	26	885	63
	27	981	40
	28	629	57
	29	690	65
	30	764	73
	31	518	73
	32	561	75
	33	606	80
	34	800	79
	35	556	46
	36	510	67
	37	502	81
	38	474	86
	39	392	92
	40	620	60
	41	559	71
	42	671	71
	43	537	75
	44	496	60
	45	727	81
	46	514	81
	47	576	76
	48	607	65

TABLE X. EXPERIMENTAL RESULTS, SUBJECT 2

SUBJECT 03	Run Number	Error score	EMG total(x10)
	1	4767	37
Left-handed	2	2584	36
	3	3909	39
31 years old	4	2670	37
	5	1348	33
Private pilot	6	1629	25
	7	2237	36
Active biofeedback	8	1988	39
except as	9	1540	36
indicated (*)	10	1373	36
	11	1433	37
	12	1587	39
	13	1311	36
	14	1470	37
	15	1705	38
	16	1674	42
	17	1099	36
	18	1297	36
	19	1465	38
	20	1246	36
	21	1186	30
	22	990	33
	23	1112	33
	24	1449	35
	25	958	34
	26	847	34
	27	904	36
	28	1208	36
	29	1259	30
	30	607	35
	31	771	36
	32	661	36
	33	849	35
	34	975	39
	35	1095	41
	36	1020	36
	37	717	40
	38	586	42
	39	717	42
	40	686	44
	41	773	49
	42	614	45
	43	632	46
	44	656	50
	45	645	44
	46	698	45
	47	724	46
	48	512	47

TABLE XI. EXPERIMENTAL RESULTS, SUBJECT 3

SUBJECT 03
continued

Active biofeedback except as indicated (*)

Run Number	Error score	EMG total(x10)
49*	692	40
50*	573	49
51*	772	46
52*	621	46
53	639	38
54	411	38
55	754	41
56	575	42
57	520	48
58	497	48
59	597	51
60	578	52
61*	756	45
62*	583	44
63*	654	53
64*	599	70
65*	853	55
66*	625	52
67*	789	59
68*	820	56
69	747	48
70	807	47
71	685	53
72	813	53
73	892	62
74	887	67
75	1126	73
76	1125	71
77*	1176	76
78*	1224	88
79*	1649	78
80*	1071	87

TABLE XI. CONTINUED (Sheet 2 of 2)

SUBJECT 04

Right-handed

29 years old

USAF pilot

Active biofeedback except as indicated (*)

Run Number	Error score	EMG total(x10)
1	2262	39
2	2296	44
3	1404	44
4	1642	56
5	1368	46
6	1669	42
7	1520	41
8	1422	44
9	1005	51
10	987	52
11	1445	48
12	1103	43
13	1179	36
14	1058	38
15	1347	41
16	1002	40
17	1266	33
18	1000	33
19	673	36
20	642	28
21	647	36
22	840	45
23	931	46
24	1232	39
25	960	45
26	981	38
27	939	47
28	1029	43
29	857	41
30	959	38
31	1103	45
32	916	35
33	572	47
34	545	44
35	573	35
36	592	37
37	519	35
38	641	37
39	662	37
40	797	35
41	477	43
42	532	56
43	763	54
44	683	46
45	679	36
46	827	54
47	818	53
48	673	58

TABLE XII. EXPERIMENTAL RESULTS, SUBJECT 4

SUBJECT 04
continued

Active biofeedback
except as
indicated (*)

Run Number	Error score	EMG total(x10)
49*	884	43
50*	839	53
51*	835	52
52*	708	52
53	739	33
54	775	39
55	708	53
56	716	57
57	782	61
58	735	56
59*	739	63
60*	652	65
61*	606	62
62*	648	77
63*	900	72
64*	544	59
65*	640	72
66*	694	68
67*	726	55
68	846	67
69	763	66
70	682	66
71	686	67
72	602	67
73	604	70
74	672	74
75*	702	55
76*	665	82
77*	926	99
78*	538	95

TABLE XII. CONTINUED (Sheet 2 of 2)

SUBJECT 05	Run Number	Error score	EMG total(x10)
	1	7967	79
Right-handed	2	9396	72
	3	8276	74
34 years old	4	7613	69
	5	7660	66
Tracking	6	8172	75
experience	7	8970	64
	8	5433	70
Biofeedback	9	4223	72
training only	10	4221	62
	11	4888	63
	12	3840	64
	13	3927	79
	14	3173	98
	15	3844	85
	16	4025	96
	17	3315	82
	18	2785	80
	19	2487	82
	20	3043	96
	21	2375	78
	22	2369	87
	23	3234	103
	24	3713	127
	25	2958	97
	26	1739	64
	27	2214	83
	28	2490	86
	29	2541	71
	30	1859	78
	31	1943	83
	32	2269	94
	33	1591	84
	34	1518	68
	35	1245	65
	36	1981	69
	37	1824	78
	38	1421	64
	39	1724	66
	40	1539	60
	41	1617	91
	42	1860	83
	43	1757	93
	44	1435	80
	45	1628	91
	46	1664	100
	47	2591	101
	48	2139	88

TABLE XIII. EXPERIMENTAL RESULTS, SUBJECT 5

SUBJECT 06	Run Number	Error score	EMG total(x10)
	1	1736	45
Right-handed	2	1534	49
	3	1323	37
23 years old	4	1004	28
	5	678	29
Private pilot	6	840	37
	7	807	33
Active biofeedback	8	829	31
	9	698	29
	10	633	36
	11	719	39
	12	511	36
	13	580	33
	14	445	39
	15	507	36
	16	569	38
	17	691	33
	18	601	36
	19	479	36
	20	432	40
	21	396	29
	22	519	36
	23	586	39
	24	512	35
	25	771	36
	26	623	41
	27	779	38
	28	535	34
	29	484	25
	30	540	31
	31	789	29
	32	647	37
	33	499	38
	34	365	42
	35	424	51
	36	433	38
	37	450	33
	38	404	44
	39	529	43
	40	577	48
	41	568	39
	42	517	42
	43	527	42
	44	650	48
	45	554	31
	46	519	40
	47	1051	46
	48	572	45

TABLE XIV. EXPERIMENTAL RESULTS, SUBJECT 6

SUBJECT 07

Right-handed

24 years old

No pilot experience

Active biofeedback as indicated (*)

Run Number	Error score	EMG total(x10)
1	3294	50
2	1796	62
3	1088	58
4	920	52
5	865	43
6	997	45
7	874	46
8	742	47
9	682	42
10	625	58
11	614	54
12	442	47
13	445	39
14	514	44
15	437	49
16	571	43
17	478	54
18	365	47
19	443	52
20	575	49
21	407	42
22	301	49
23	330	52
24	382	52
25	402	40
26	513	45
27	424	42
28	454	43
29	290	49
30	270	43
31	299	42
32	345	41
33	337	49
34	320	43
35	368	44
36	233	68
37	326	44
38	283	47
39	528	50
40	677	53
41	342	46
42	308	45
43	294	48
44	308	45
45	340	39
46	252	48
47	279	52
48	333	49

TABLE XV. EXPERIMENTAL RESULTS, SUBJECT 7

SUBJECT 07 continued	Run Number	Error score	EMG total(x10)
	49	300	44
	50	276	46
Active biofeedback as indicated (*)	51	247	48
	52	261	49
	53*	272	39
	54*	214	41
	55*	232	44
	56*	240	42
	57*	366	39
	58*	361	42
	59*	392	42
	60*	261	40
	61	276	42
	62	270	49
	63	249	48
	64	300	42
	65*	336	40
	66*	350	39
	67*	299	42

TABLE XV. CONTINUED (Sheet 2 of 2)

SUBJECT 08

Right-handed

25 years old

Tracking expert

Active biofeedback as indicated (*)

Run Number	Error score	EMG total(x10)
1*	2879	36
2*	1231	37
3*	1051	35
4*	1190	33
5	857	41
6	585	41
7	573	40
8	469	39
9	479	46
10	547	51
11	431	58
12	523	59
13*	685	45
14*	476	45
15*	511	44
16*	509	47
17*	533	36
18*	561	37
19*	480	34
20*	477	38
21	315	33
22	312	37
23	347	39
24	356	39
25	360	42
26	331	45
27	348	51
28	320	53
29*	281	35
30*	315	49
31*	310	44
32*	275	40
33*	293	33
34*	304	35
35*	277	35
36*	336	35
37	273	33
38	312	33
39	210	31
40	250	38
41	263	36
42	307	55
43	319	35
44	293	40
45*	265	30
46*	289	35
47*	301	36
48*	308	33

TABLE XVI. EXPERIMENTAL RESULTS, SUBJECT 8

SUBJECT 09	Run Number	Error score	EMG total(x10)
	1	3080	48
Right-handed	2	3397	37
	3	3346	47
28 years old	4	3085	43
	5	1574	34
Some pilot	6	1797	37
experience	7	1638	39
	8	1073	33
Biofeedback	9	1498	36
training only	10	2925	38
	11	2568	33
	12	1514	33
	13	1399	27
	14	1335	31
	15	1688	32
	16	1168	32
	17	747	33
	18	1061	34
	19	937	34
	20	944	36
	21	815	38
	22	580	35
	23	836	30
	24	839	35
	25	628	33
	26	562	30
	27	861	28
	28	878	30
	29	583	24
	30	991	31
	31	656	27
	32	872	28
	33	501	28
	34	495	30
	35	472	29
	36	441	27
	37	621	28
	38	382	33
	39	511	33
	40	580	38
	41	737	31
	42	710	33
	43	527	33
	44	571	33
	45	519	35
	46	547	35
	47	495	32
	48	404	33

TABLE XVII. EXPERIMENTAL RESULTS, SUBJECT 9

SUBJECT 10

Right-handed

22 years old

No pilot experience

Active biofeedback

Run Number	Error score	EMG total(x10)
1	3071	42
2	2504	46
3	1807	48
4	2021	49
5	1059	41
6	1058	48
7	1123	49
8	1353	61
9	799	42
10	1088	52
11	1111	43
12	817	54
13	860	55
14	598	61
15	706	50
16	705	55
17	629	40
18	699	51
19	701	76
20	713	61
21	806	44
22	534	63
23	628	92
24	779	94
25	757	43
26	757	45
27	930	65
28	968	59
29	1213	52
30	627	61
31	1014	69
32	1281	43
33	465	38
34	759	49
35	725	57
36	796	62
37	811	35
38	653	63
39	589	77
40	1149	79
41	718	41
42	1088	58
43	919	74
44	1418	66
45	982	57
46	934	63
47	1194	75
48	820	74

TABLE XVIII. EXPERIMENTAL RESULTS, SUBJECT 10

SUBJECT 11	Run Number	Error score	EMG total(x10)
	1	575	69
Right-handed	2	515	73
	3	588	69
33 years old	4	533	80
	5*	433	49
Tracking expert	6*	345	61
	7*	460	63
Active biofeedback	8*	575	60
as indicated (*)	9*	325	66
	10*	334	71
	11*	401	76
	12*	540	77
	13	291	56
	14	368	64
	15	304	66
	16	418	67
	17	284	58
	18	414	61
	19	394	66
	20	245	64
	21*	261	58
	22*	289	63
	23*	321	65
	24*	283	69
	25*	603	63
	26*	229	69
	27*	305	68
	28*	279	77
	29	260	65
	30	254	67
	31	329	73
	32	305	74
	33	314	64
	34	272	77
	35	302	76
	36	403	74
	37*	221	63
	38*	296	75
	39*	273	78
	40*	360	85
	41*	315	60
	42*	276	66
	43*	263	69
	44*	215	69
	45	233	46
	46	330	52
	47	263	61
	48	340	64

TABLE XIX. EXPERIMENTAL RESULTS, SUBJECT 11

SUBJECT 11 continued	Run Number	Error score	EMG total(x10)
	49	246	50
	50	215	59
Active biofeedback as indicated (*)	51	283	63
	52	352	55
	53*	222	45
	54*	324	58
	55*	351	61
	56*	205	61
	57*	277	55
	58*	264	60
	59*	258	60
	60*	310	64
	61	224	52
	62	279	53
	63	289	54
	64	378	61
	65	233	51
	66	234	53
	67	255	55
	68	226	59
	69*	243	45
	70*	272	48
	71*	191	54
	72*	207	57
	73*	216	53
	74*	207	58
	75*	214	58
	76*	224	59
	77	240	53
	78	missing:	thumb cramp
	79	236	58
	80	252	55

TABLE XIX. CONTINUED (Sheet 2 of 2)

SUBJECT 12

Right-handed

33 years old

Some pilot experience

No biofeedback training

Run Number	Error score	EMG total(x10)
1	5295	105
2	2678	102
3	2590	106
4	2074	110
5	1267	90
6	1522	88
7	1700	118
8	1588	111
9	920	84
10	894	91
11	797	88
12	850	79
13	660	66
14	637	69
15	650	75
16	501	78
17	707	84
18	615	84
19	793	86
20	608	84
21	463	78
22	701	92
23	629	87
24	576	84
25	709	90
26	798	106
27	429	94
28	509	98
29	504	62
30	427	65
31	381	66
32	325	95
33	501	82
34	386	91
35	349	122
36	307	127
37	373	76
38	309	89
39	369	95
40	303	96
41	462	89
42	293	100
43	309	91
44	404	79
45	570	65
46	317	72
47	323	91
48	278	102

TABLE XX. EXPERIMENTAL RESULTS, SUBJECT 12

SUBJECT 13

Right-handed

34 years old

No pilot experience

No biofeedback training

Run Number	Error score	EMG total(x10)
1	4134	56
2	4026	51
3	3590	62
4	3696	59
5	3943	60
6	2371	61
7	1829	112
8	1976	75
9	868	63
10	984	82
11	1082	100
12	1025	77
13	728	63
14	723	66
15	1082	116
16	1007	126
17	767	54
18	810	63
19	901	65
20	797	144
21	692	75
22	736	66
23	811	94
24	777	185
25	619	68
26	641	83
27	590	112
28	537	128
29	399	79
30	490	57
31	544	91
32	386	160
33	545	71
34	583	86
35	496	99
36	480	132
37	485	69
38	476	78
39	466	107
40	494	109
41	355	55
42	519	58
43	414	78
44	411	58
45	412	79
46	318	149
47	412	96
48	394	78

TABLE XXI. EXPERIMENTAL RESULTS, SUBJECT 13

SUBJECT 14

Right-handed

32 years old

USAF pilot

Biofeedback
training only

Run Number	Error score	EMG total(x10)
1	2352	64
2	3496	64
3	4364	64
4	4291	72
5	3920	64
6	2974	58
7	2054	72
8	2431	70
9	1382	67
10	1200	81
11	1600	80
12	1609	83
13	862	70
14	1068	80
15	1599	80
16	1557	80
17	1138	67
18	1098	88
19	916	85
20	802	87
21	834	62
22	665	75
23	923	76
24	645	81
25	918	70
26	954	76
27	855	80
28	995	120
29	868	63
30	924	74
31	816	72
32	695	98
33	553	65
34	753	78
35	556	74
36	508	73
37	579	46
38	770	72
39	525	66
40	452	64
41	658	73
42	667	75
43	735	79
44	667	86
45	728	58
46	657	70
47	745	83
48	714	77

TABLE XXII. EXPERIMENTAL RESULTS, SUBJECT 14

SUBJECT 15

Right-handed

32 years old

No pilot experience

No biofeedback training

Run Number	Error score	EMG total(x10)
1	6918	158
2	4239	168
3	4392	171
4	3671	160
5	1614	146
6	1574	183
7	2755	209
8	2654	168
9	1195	204
10	1306	233
11	1274	252
12	1239	295
13	829	244
14	1430	278
15	1119	267
16	952	298
17	507	225
18	729	244
19	702	251
20	511	245
21	527	186
22	428	232
23	476	191
24	689	209
25	440	171
26	557	207
27	427	210
28	538	220
29	422	156
30	473	222
31	482	187
32	534	228
33	702	201
34	627	221
35	613	191
36	837	193
37	527	103
38	591	157
39	484	136
40	517	139
41	465	222
42	460	244
43	706	213
44	338	166
45	343	180
46	417	175
47	403	177
48	390	174

TABLE XXIII. EXPERIMENTAL RESULTS, SUBJECT 15

SUBJECT 16	Run Number	Error score	EMG total(x10)
	1	8026	83
Right-handed	2	6356	78
	3	4176	70
30 years old	4	3858	65
	5	2920	61
No pilot	6	3447	73
experience	7	3896	75
	8	2933	77
Active biofeedback	9	2781	73
	10	2990	90
	11	2769	71
	12	2352	91
	13	2088	71
	14	2184	90
	15	1750	78
	16	2044	90
	17	2858	81
	18	2646	88
	19	3333	96
	20	3005	110
	21	3051	78
	22	2223	93
	23	2268	99
	24	2852	107
	25	2063	78
	26	1845	87
	27	1865	99
	28	2562	103
	29	1792	77
	30	1556	81
	31	1819	90
	32	2043	99
	33	1082	81
	34	2413	86
	35	1490	87
	36	1223	95
	37	1002	63
	38	1335	96
	39	1594	110
	40	1656	107
	41	1119	98
	42	1447	111
	43	1294	115
	44	1190	119
	45	1232	98
	46	1348	114
	47	1379	126
	48	907	132

TABLE XXIV. EXPERIMENTAL RESULTS, SUBJECT 16

SUBJECT 17	Run Number	Error score	EMG total(x10)
	1	7162	89
Right-handed	2	4603	87
	3	3277	93
28 years old	4	2996	101
	5	2446	89
No pilot	6	3188	102
experience	7	2919	101
	8	3758	108
No biofeedback	9	3627	68
training	10	3413	67
	11	3397	73
	12	3057	75
	13	2901	67
	14	2734	74
	15	2360	83
	16	2544	78
	17	2615	68
	18	1969	71
	19	1608	82
	20	1237	79
	21	1782	69
	22	844	81
	23	1414	90
	24	1134	84
	25	1224	73
	26	1278	72
	27	1436	73
	28	1199	111
	29	1559	74
	30	1290	79
	31	1565	102
	32	1369	87
	33	2246	72
	34	1240	75
	35	1387	76
	36	1585	73
	37	1484	69
	38	1428	73
	39	970	84
	40	1278	79
	41	1354	69
	42	1016	71
	43	1061	78
	44	929	79
	45	1198	77
	46	873	74
	47	867	74
	48	1409	76

TABLE XXV. EXPERIMENTAL RESULTS, SUBJECT 17

SUBJECT 18

Right-handed

36 years old

No pilot experience

Active biofeedback

Run Number	Error score	EMG total(x10)
1	6172	57
2	5169	54
3	3337	50
4	2247	61
5	1628	47
6	1363	46
7	984	50
8	1035	62
9	1309	50
10	1234	53
11	1019	55
12	824	56
13	680	51
14	966	55
15	779	58
16	758	55
17	873	70
18	788	64
19	583	56
20	570	54
21	647	44
22	550	45
23	600	48
24	585	47
25	616	49
26	640	46
27	553	47
28	486	48
29	546	51
30	429	51
31	394	54
32	361	58
33	486	59
34	540	52
35	456	46
36	427	45
37	554	47
38	366	42
39	299	46
40	354	47
41	450	63
42	425	55
43	436	56
44	340	51
45	455	55
46	415	56
47	362	55
48	424	55

TABLE XXVI. EXPERIMENTAL RESULTS, SUBJECT 18

SUBJECT 19

Right-handed

27 years old

No pilot experience

No biofeedback training

Run Number	Error score	EMG total(x10)
1	4260	172
2	3951	191
3	3090	170
4	3564	170
5	1432	128
6	1874	138
7	2471	149
8	1253	162
9	1019	183
10	1247	187
11	836	206
12	1091	186
13	909	219
14	930	missing
15	1031	166
16	1346	215
17	603	184
18	957	210
19	924	224
20	1037	231
21	862	231
22	684	194
23	852	185
24	1092	256
25	521	110
26	581	131
27	765	155
28	959	156
29	720	132
30	528	161
31	631	171
32	561	189
33	810	154
34	805	168
35	913	158
36	936	141
37	730	138
38	806	133
39	725	141
40	875	146
41	632	105
42	577	115
43	563	136
44	739	151
45	768	90
46	530	105
47	492	123
48	504	127

TABLE XXVII. EXPERIMENTAL RESULTS, SUBJECT 19

SUBJECT 20	Run Number	Error score	EMG total(x10)
	1	4395	86
Right-handed	2	3254	67
	3	2176	77
30 years old	4	1526	82
	5	778	72
Some pilot experience	6	1257	83
	7	1543	79
	8	1395	88
Biofeedback training only	9	709	91
	10	919	93
	11	768	90
	12	768	89
	13	883	84
	14	793	90
	15	785	90
	16	813	80
	17	740	104
	18	580	100
	19	546	99
	20	603	99
	21	456	87
	22	730	94
	23	670	99
	24	779	93
	25	414	83
	26	466	80
	27	383	83
	28	457	66
	29	352	59
	30	363	71
	31	362	75
	32	452	86
	33	363	97
	34	394	100
	35	439	88
	36	379	84
	37	348	86
	38	358	100
	39	465	99
	40	375	77
	41	351	90
	42	324	97
	43	341	90
	44	458	88
	45	289	75
	46	429	68
	47	400	91
	48	402	82

TABLE XXVIII. EXPERIMENTAL RESULTS, SUBJECT 20

APPENDIX C

LEARNING CURVE SCATTER DIAGRAMS

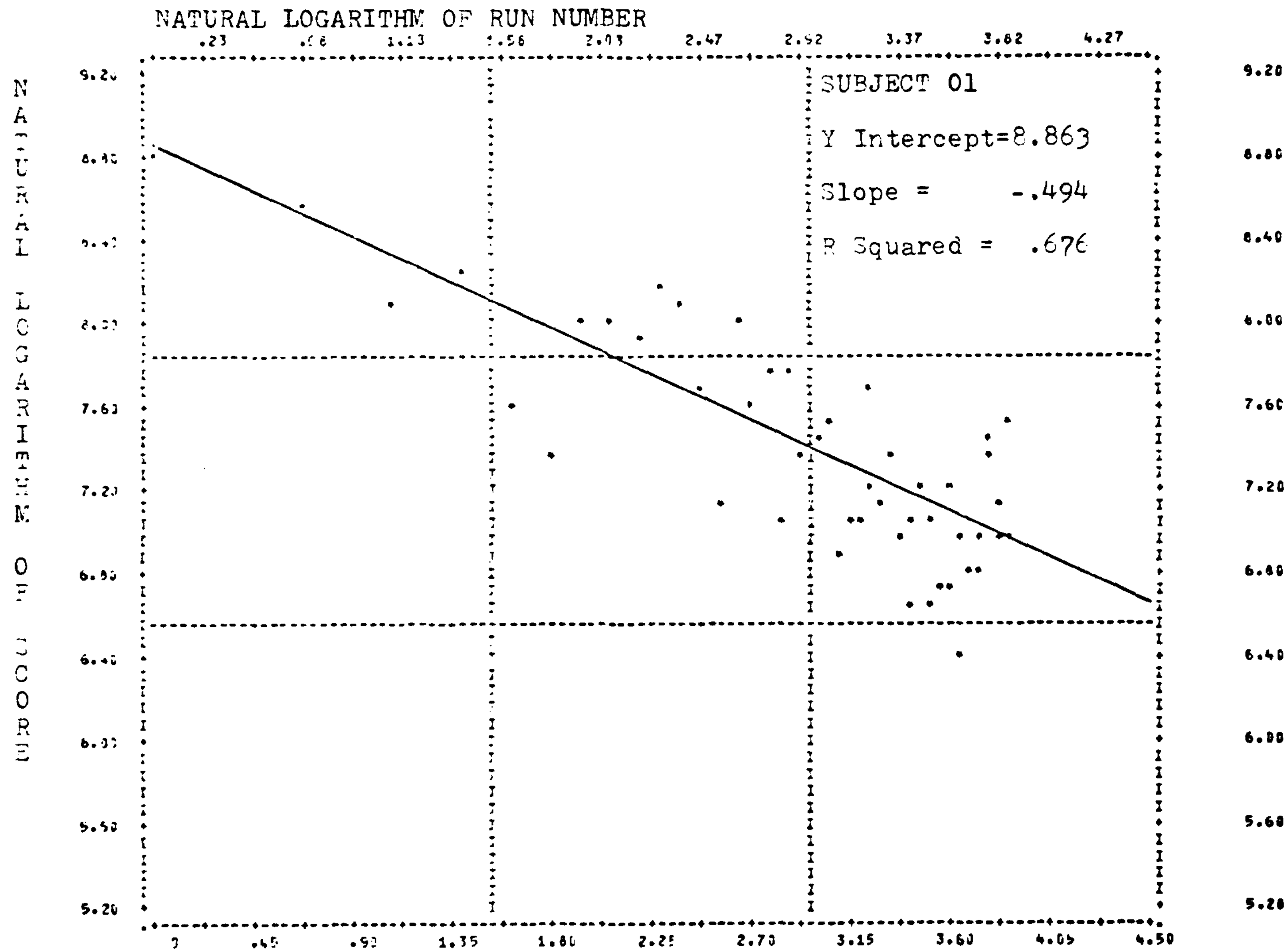


FIGURE 6. LEARNING CURVE, SUBJECT 1

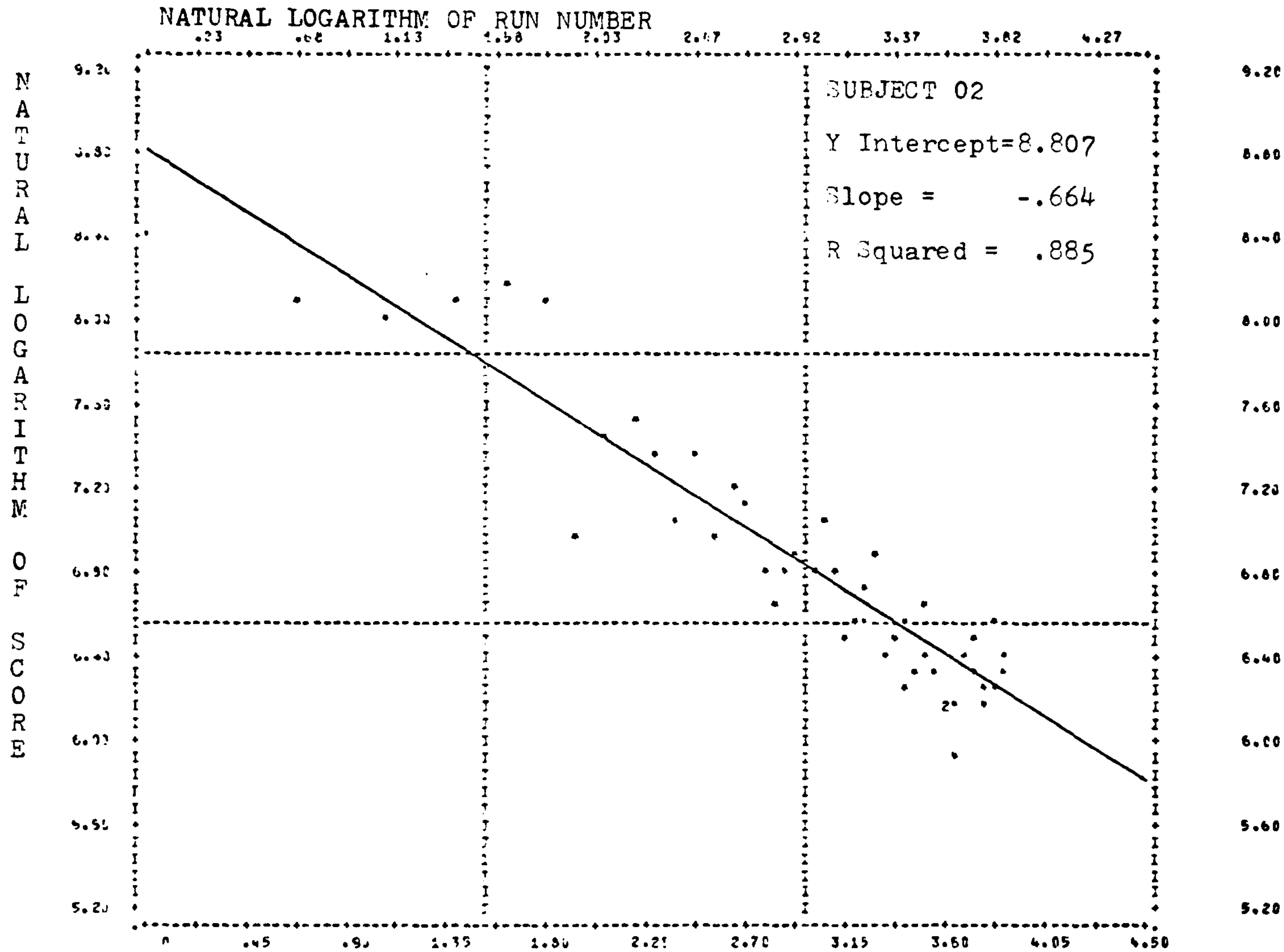


FIGURE 7. LEARNING CURVE, SUBJECT 2

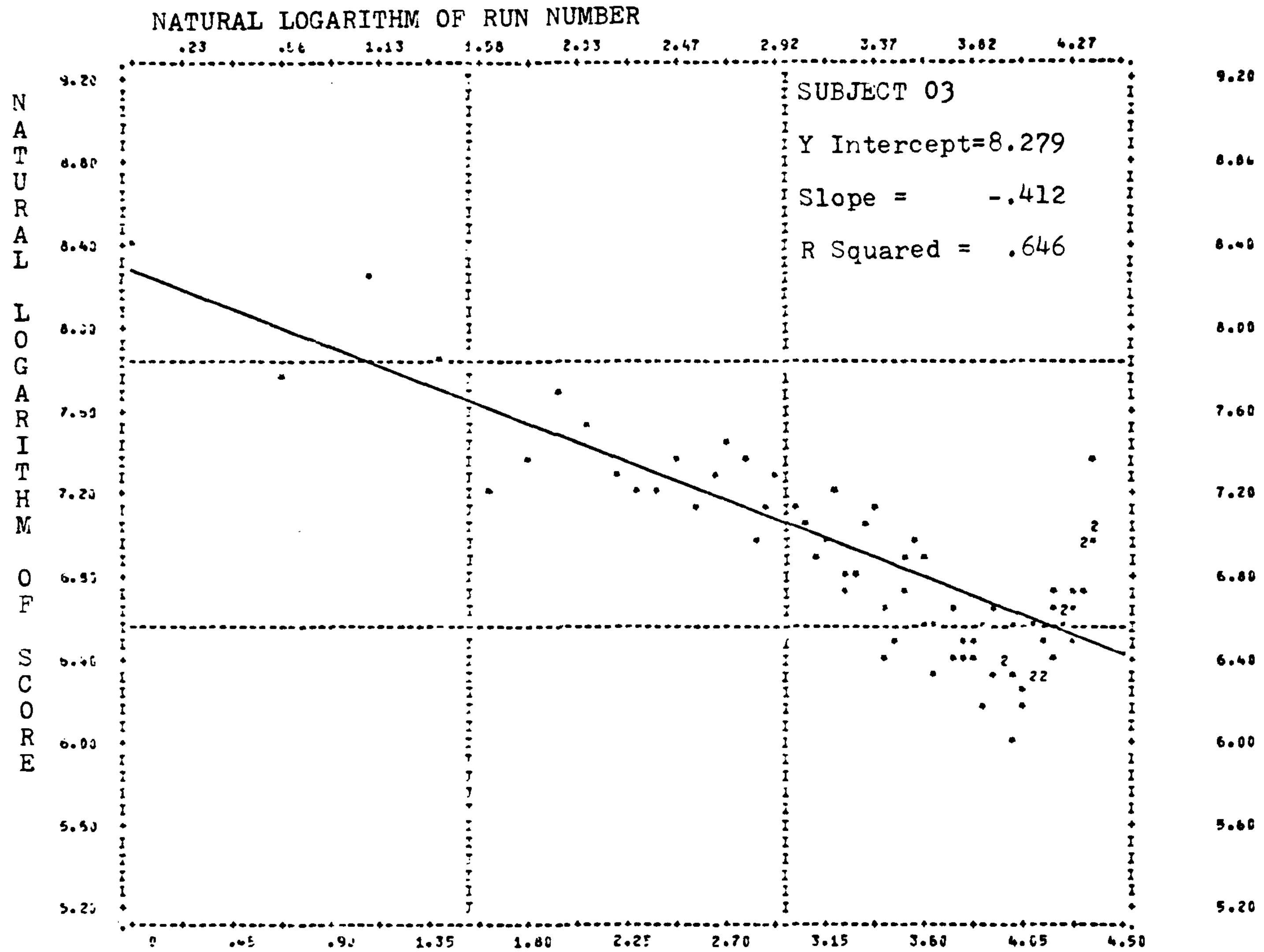


FIGURE 8. LEARNING CURVE, SUBJECT 3

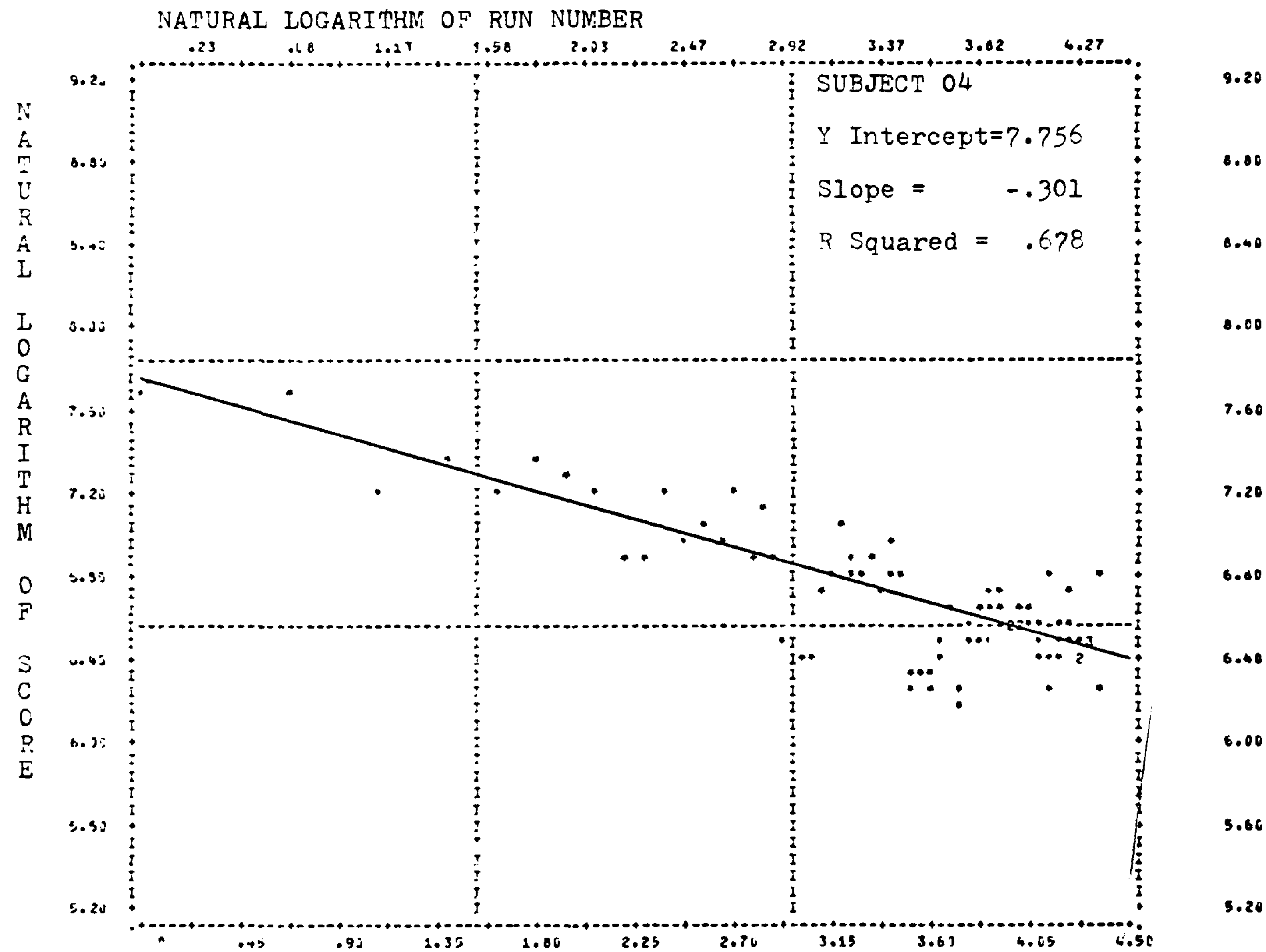


FIGURE 9. LEARNING CURVE, SUBJECT 4

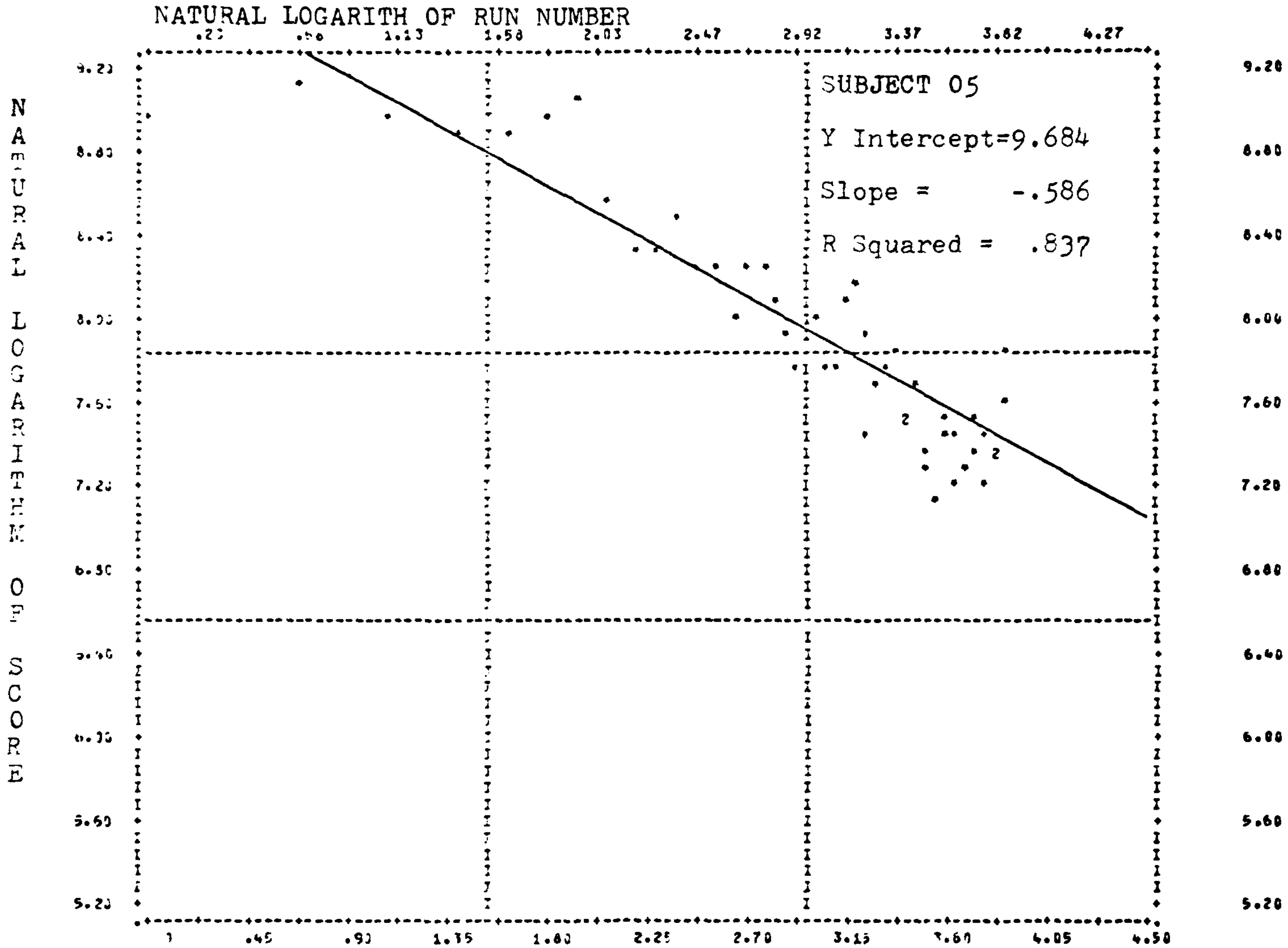


FIGURE 10. LEARNING CURVE, SUBJECT 5.

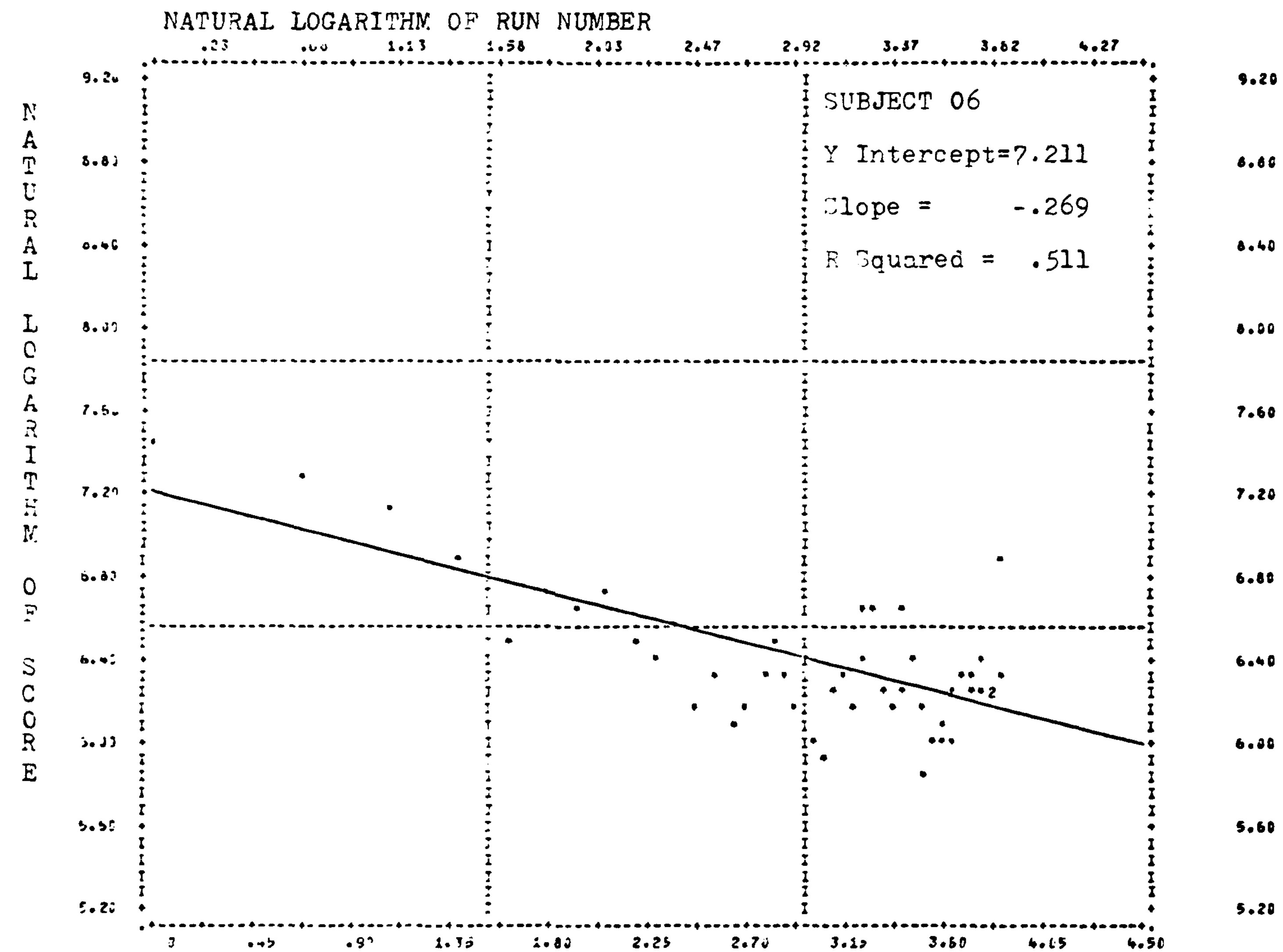


FIGURE 11. LEARNING CURVE, SUBJECT 06

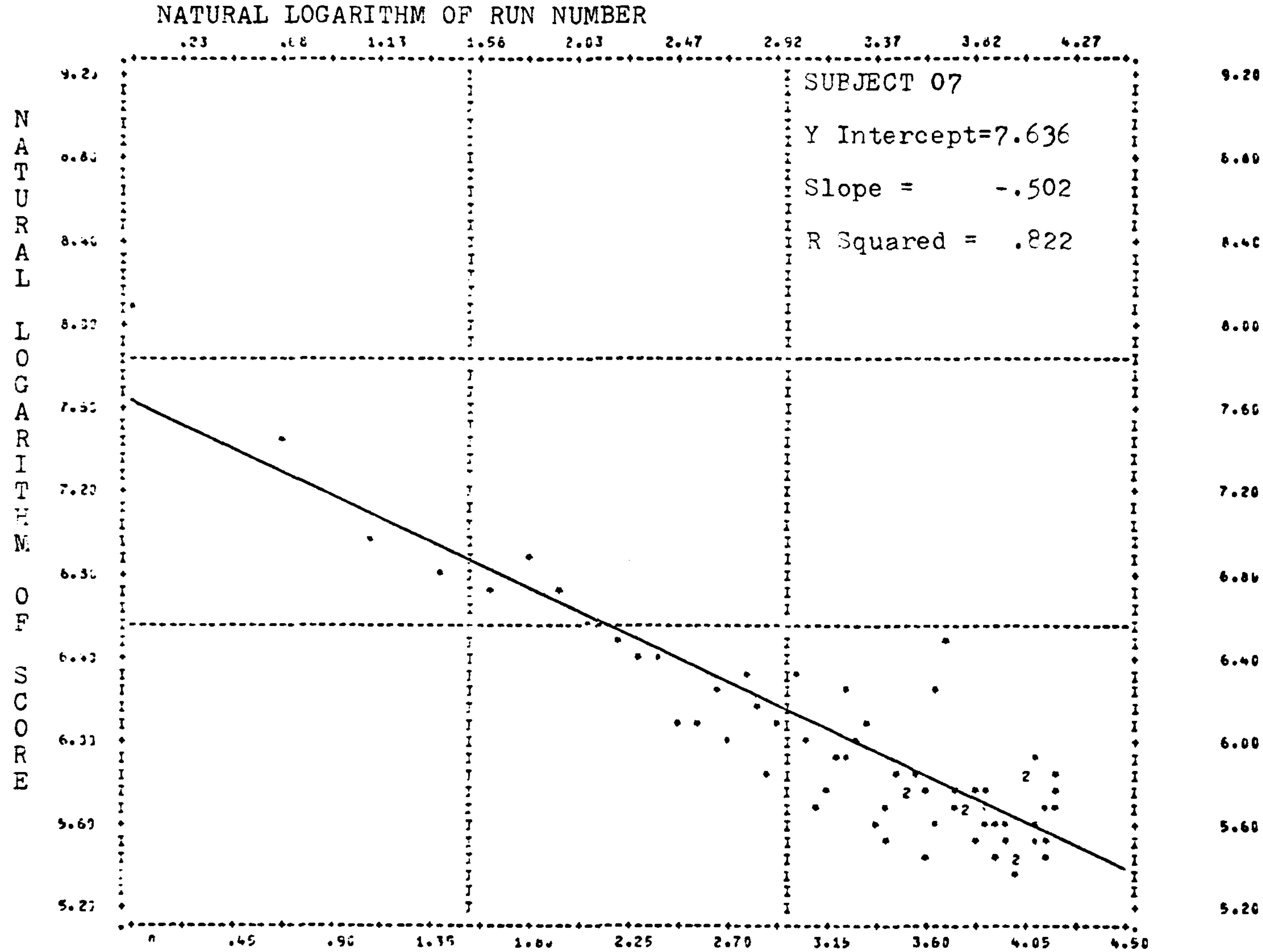


FIGURE 12. LEARNING CURVE, SUBJECT 07

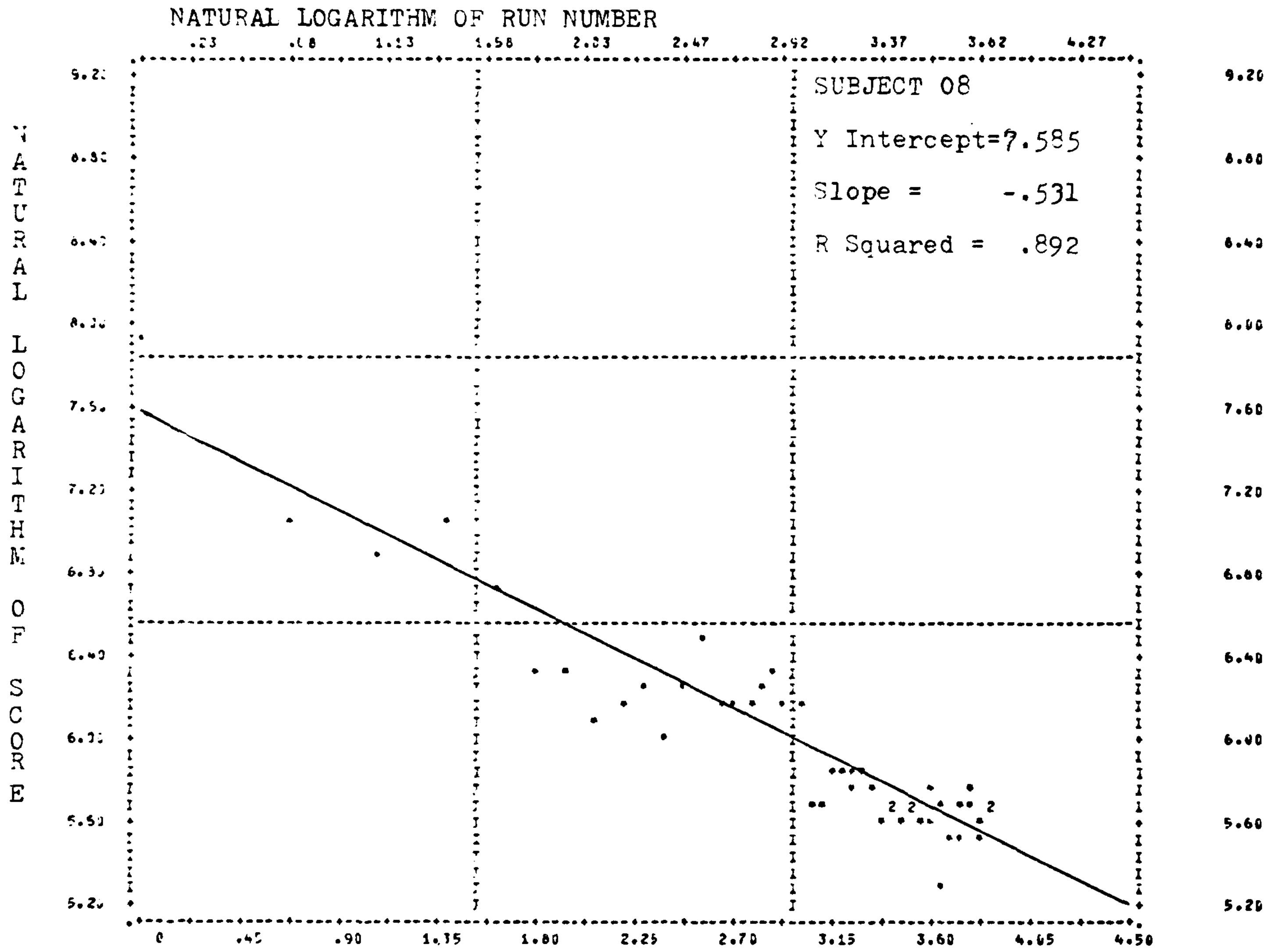


FIGURE 13. LEARNING CURVE, SUBJECT 08

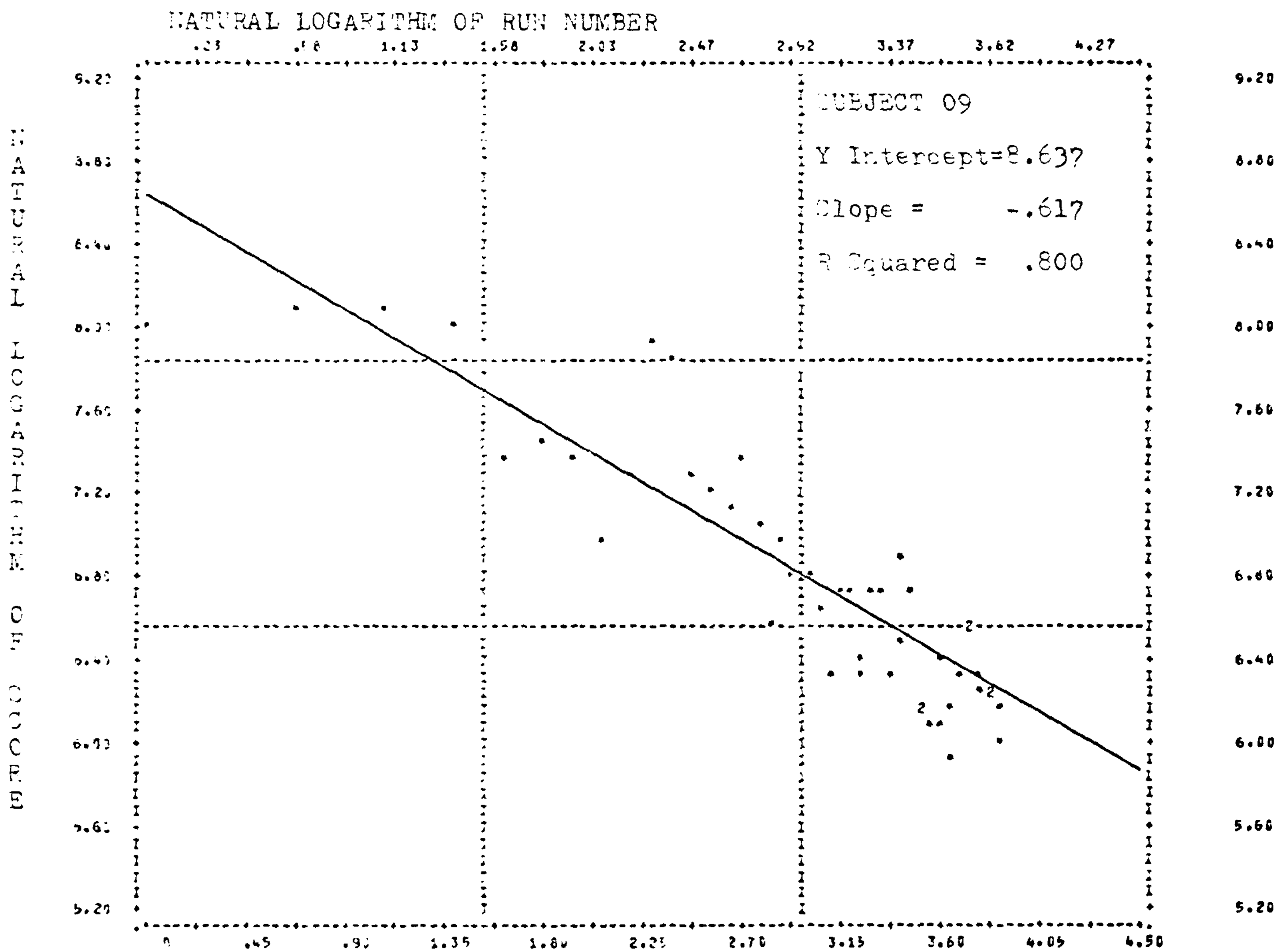


FIGURE 14. LEARNING CURVE, SUBJECT 09

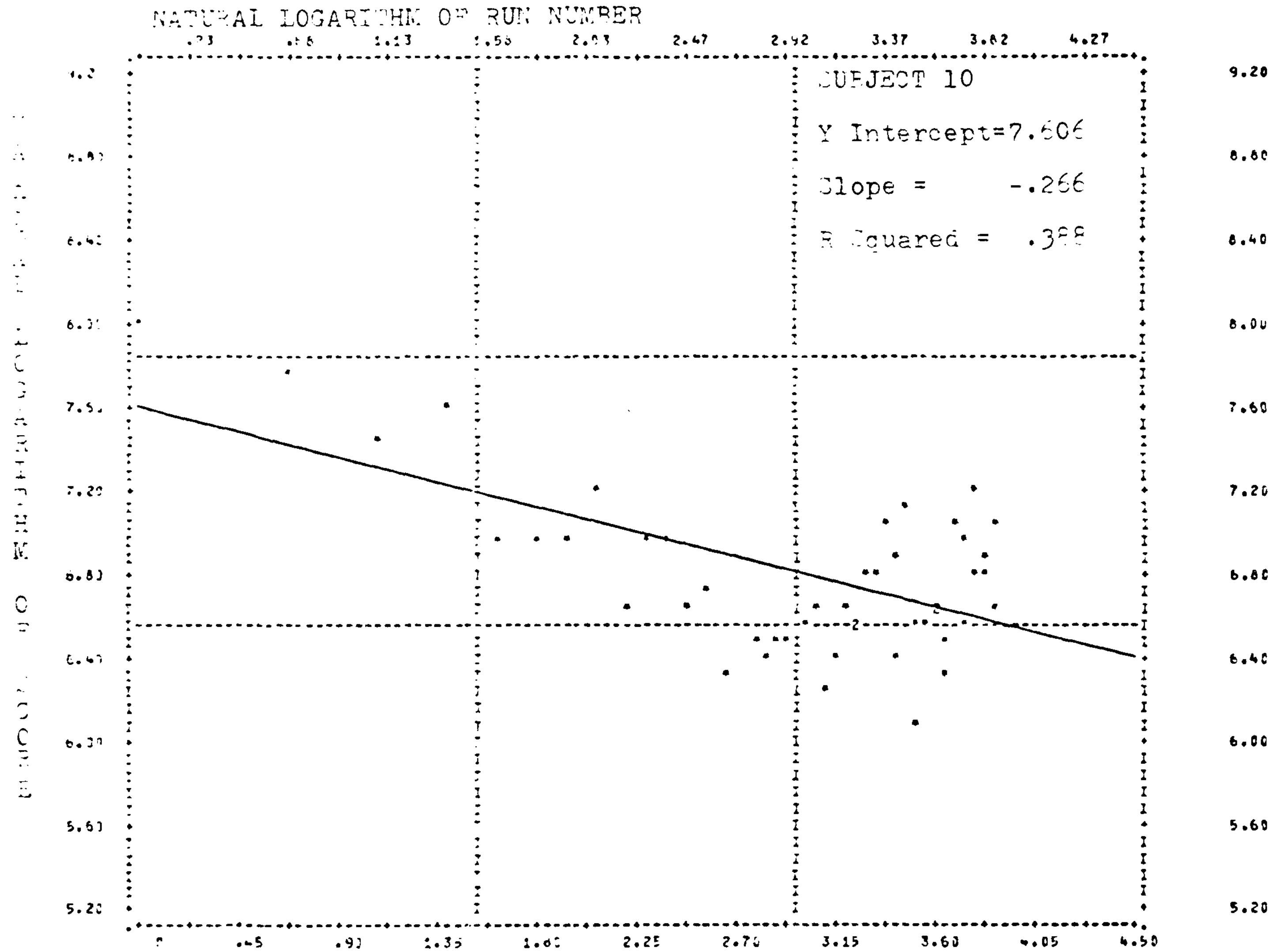
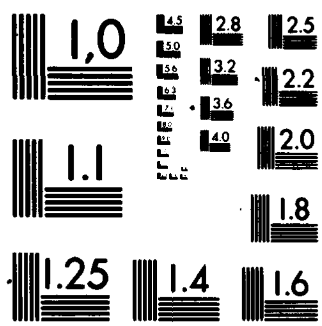


FIGURE 15. LEARNING CURVE, SUBJECT 10

AD-A083 711 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH SCHOO--ETC F/6 5/10
USE OF ELECTROMYOGRAM INFORMATION TO IMPROVE HUMAN OPERATOR PER--ETC(U)
DEC 79 M C KIPPERMAN
UNCLASSIFIED AFIT/GSM/SM/79D-18 NL

2 of 2

END
DATE FILMED
6-80
DTIC



MICROCOPY RESOLUTION TEST CHART

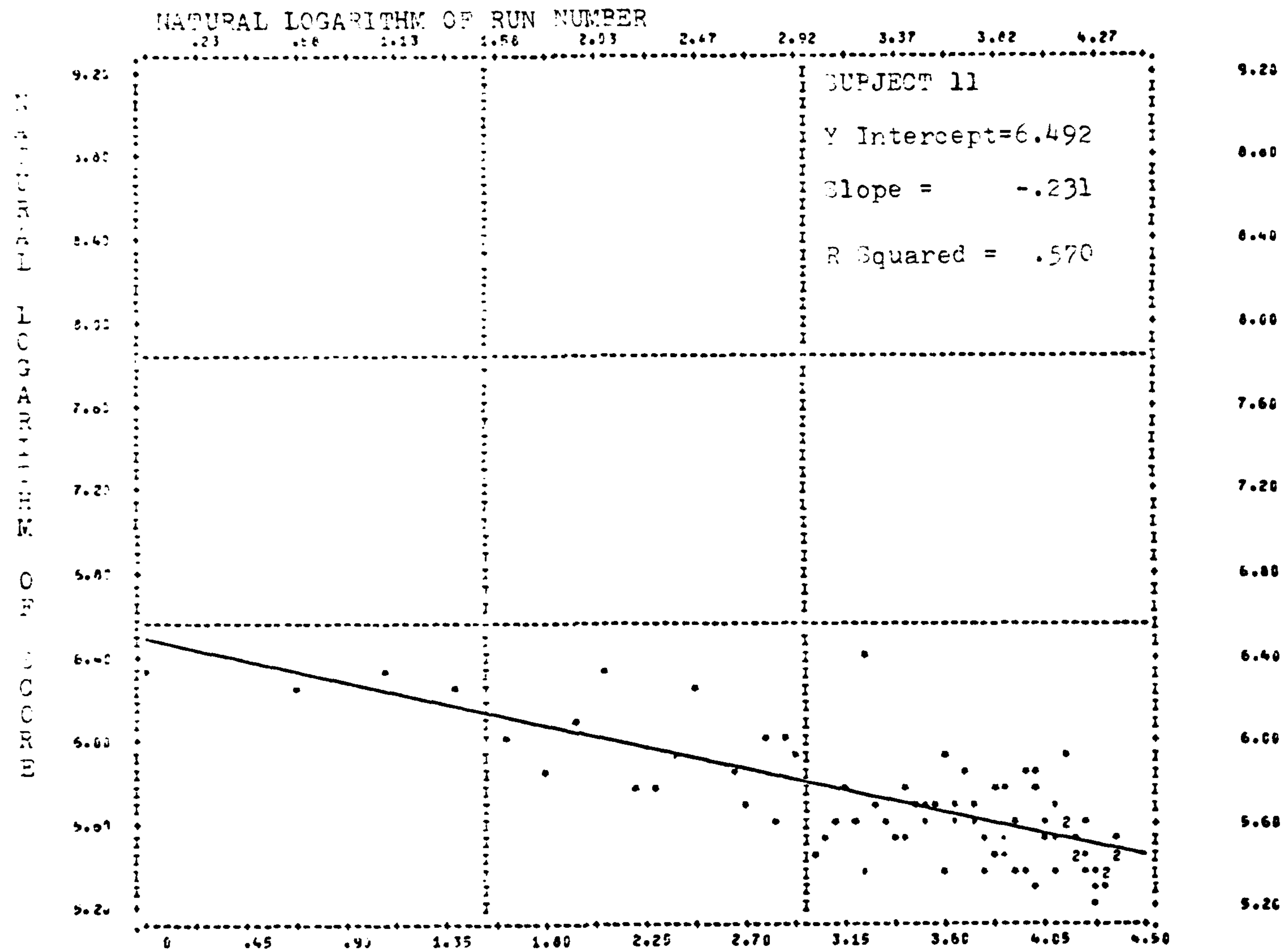


FIGURE 16. LEARNING CURVE, SUBJECT 11

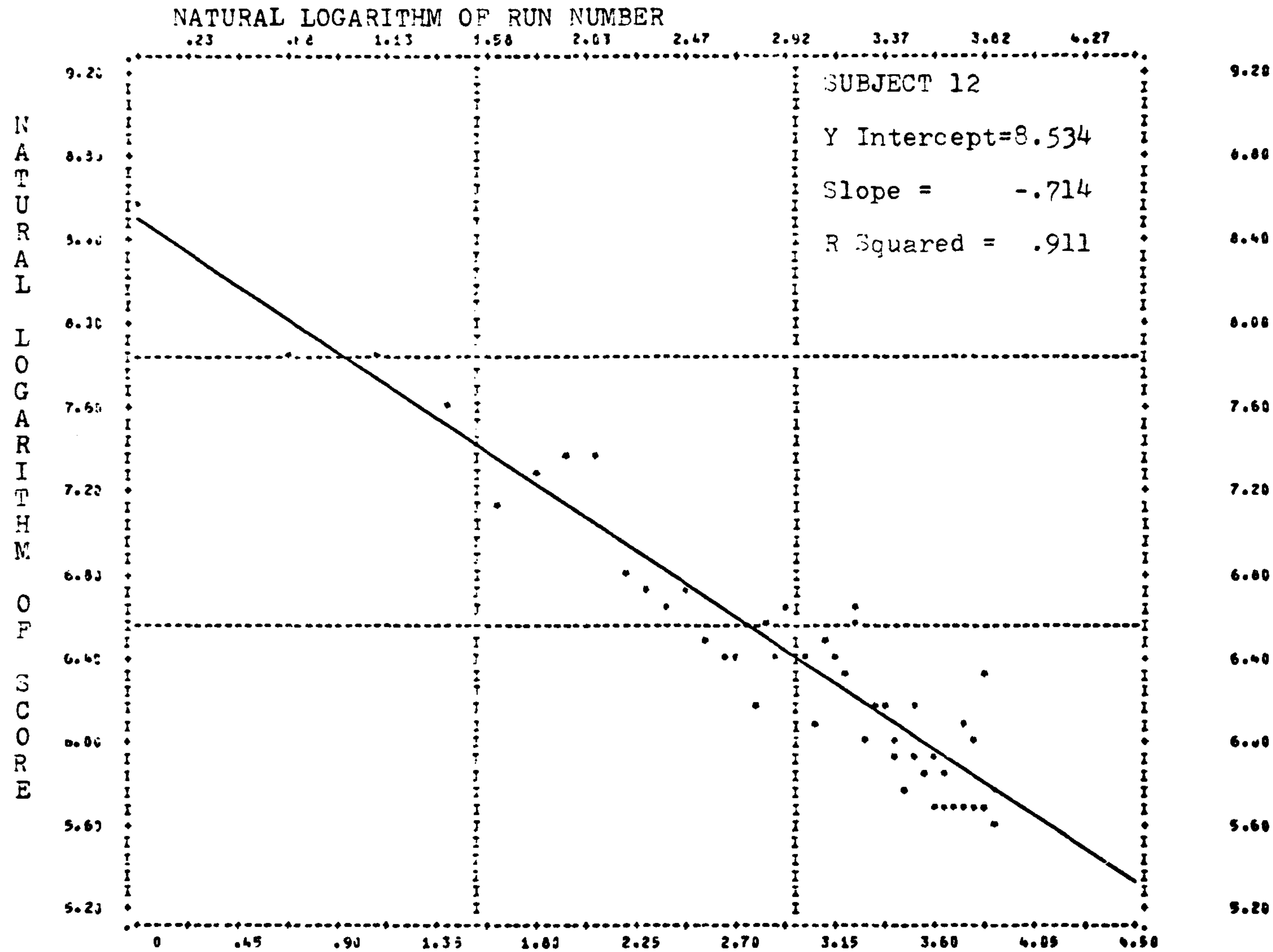


FIGURE 17. LEARNING CURVE, SUBJECT 12

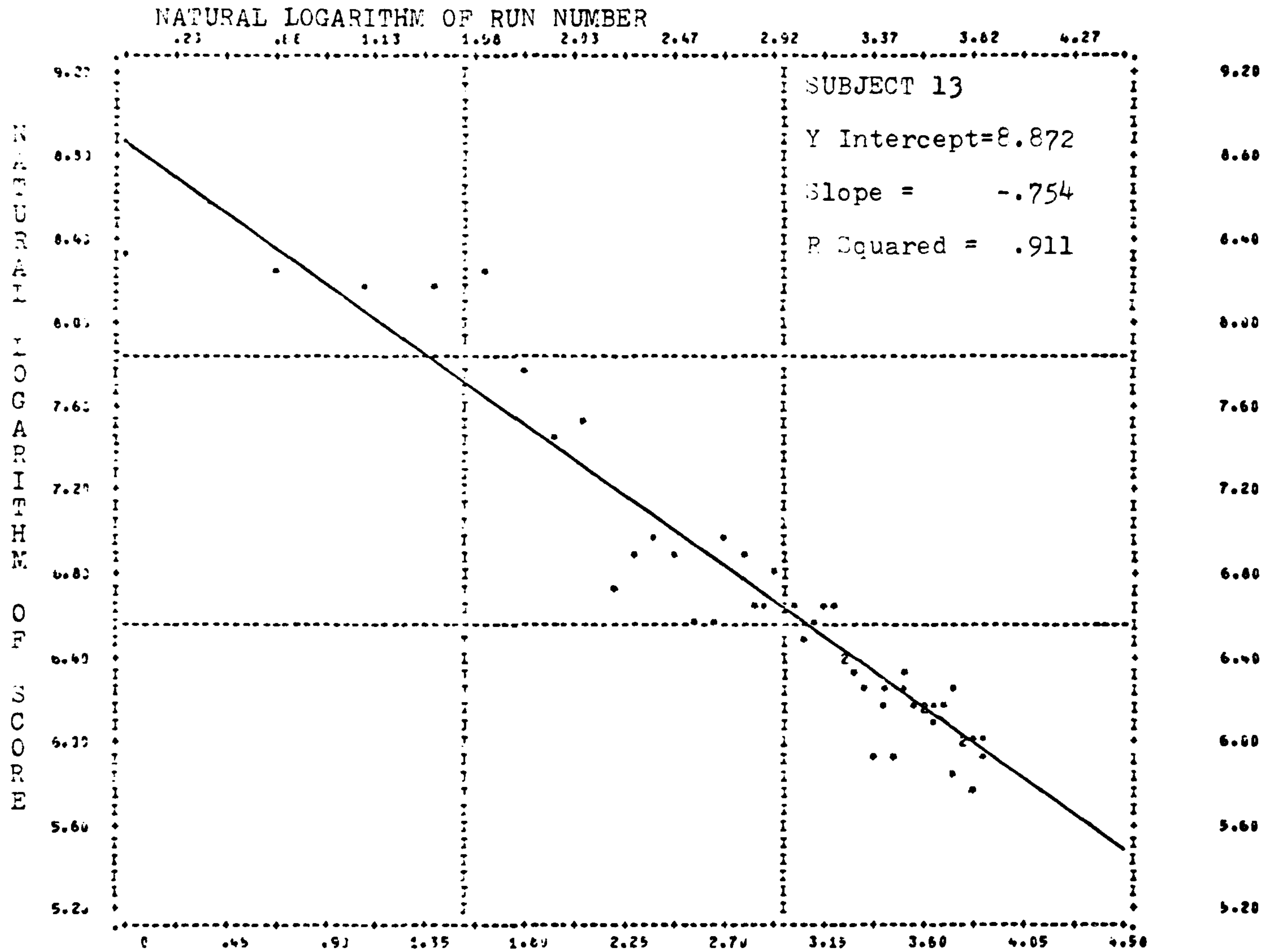


FIGURE 18. LEARNING CURVE, SUBJECT 13

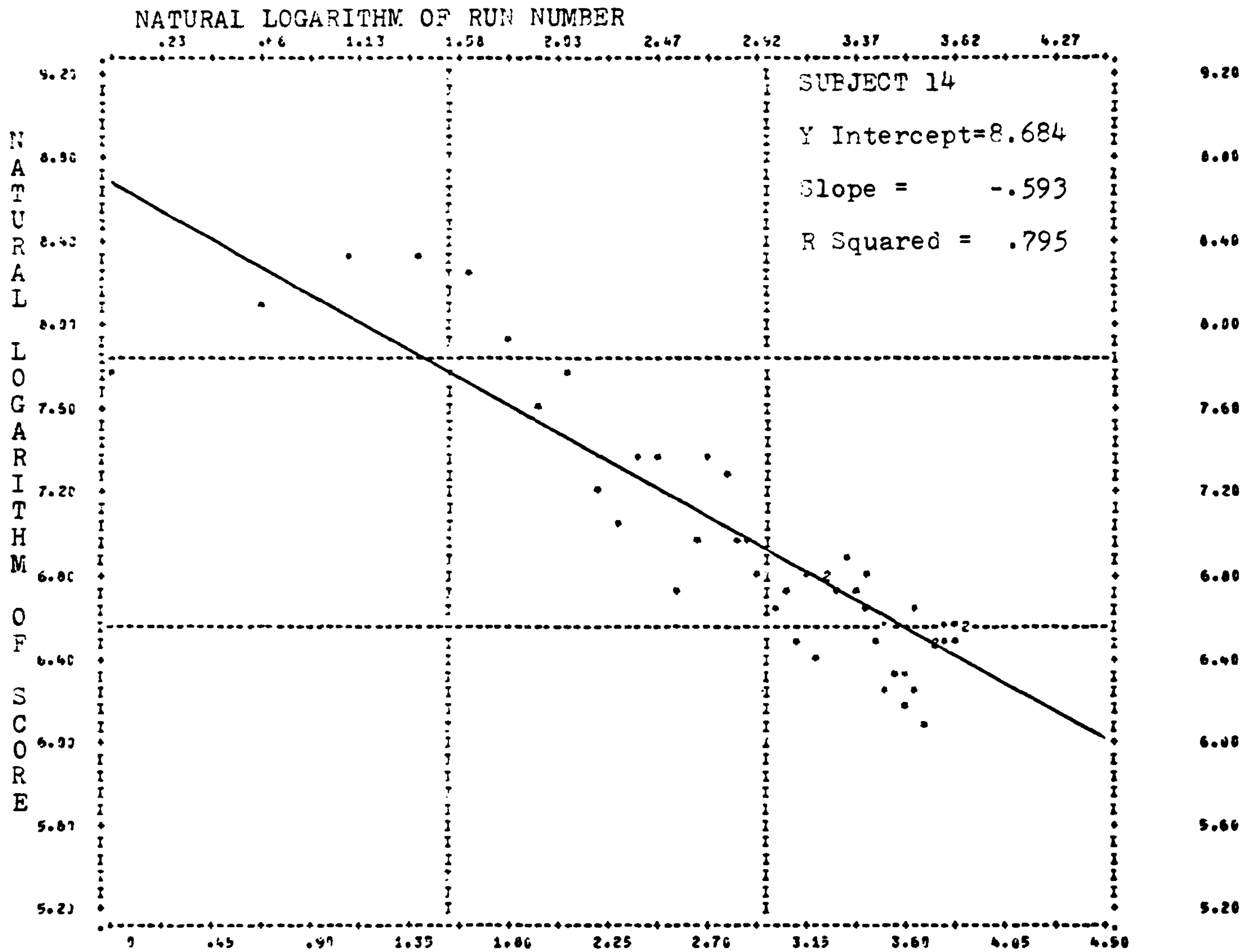


FIGURE 19. LEARNING CURVE, SUBJECT 14

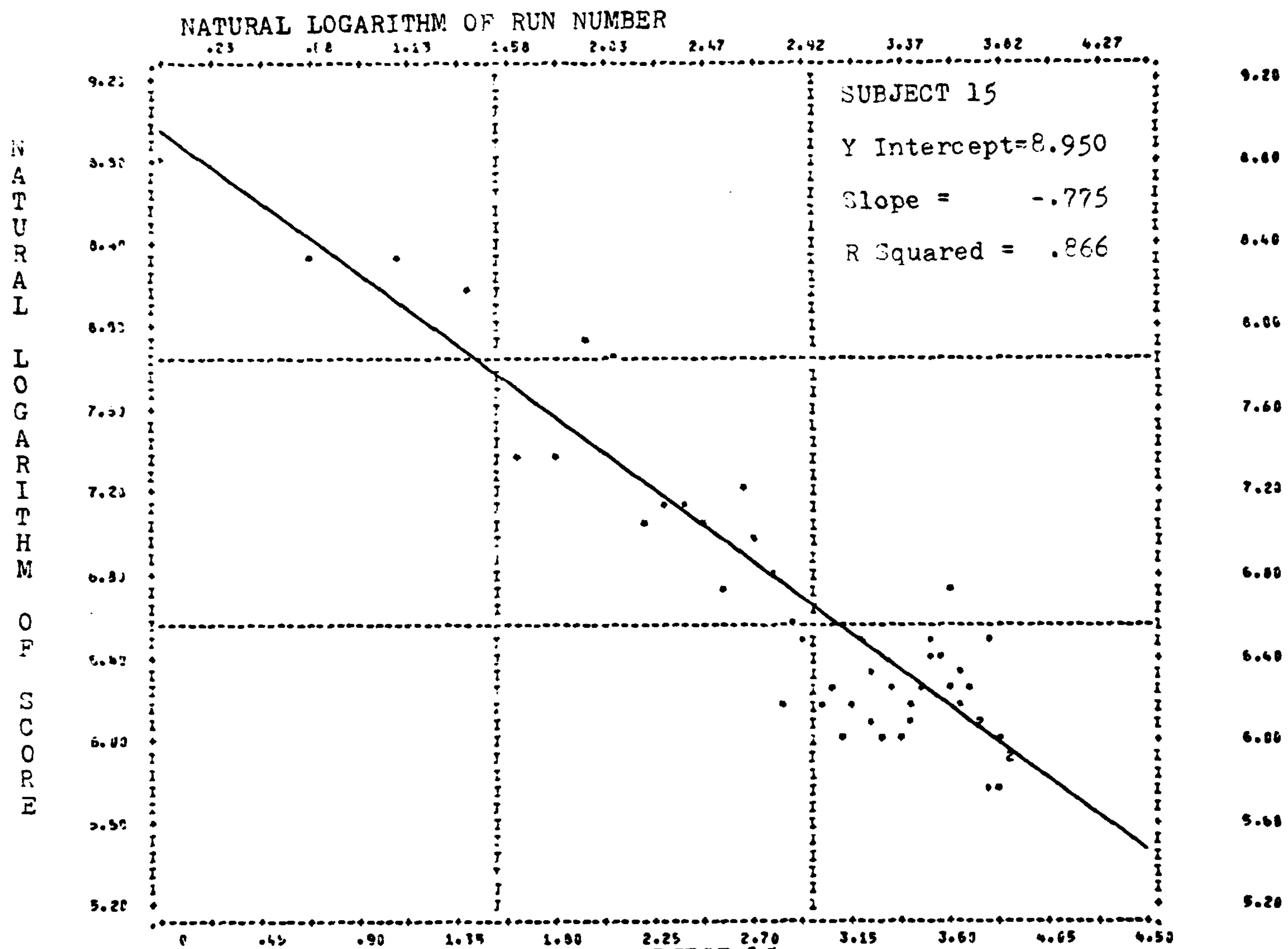


FIGURE 20. LEARNING CURVE, SUBJECT 15

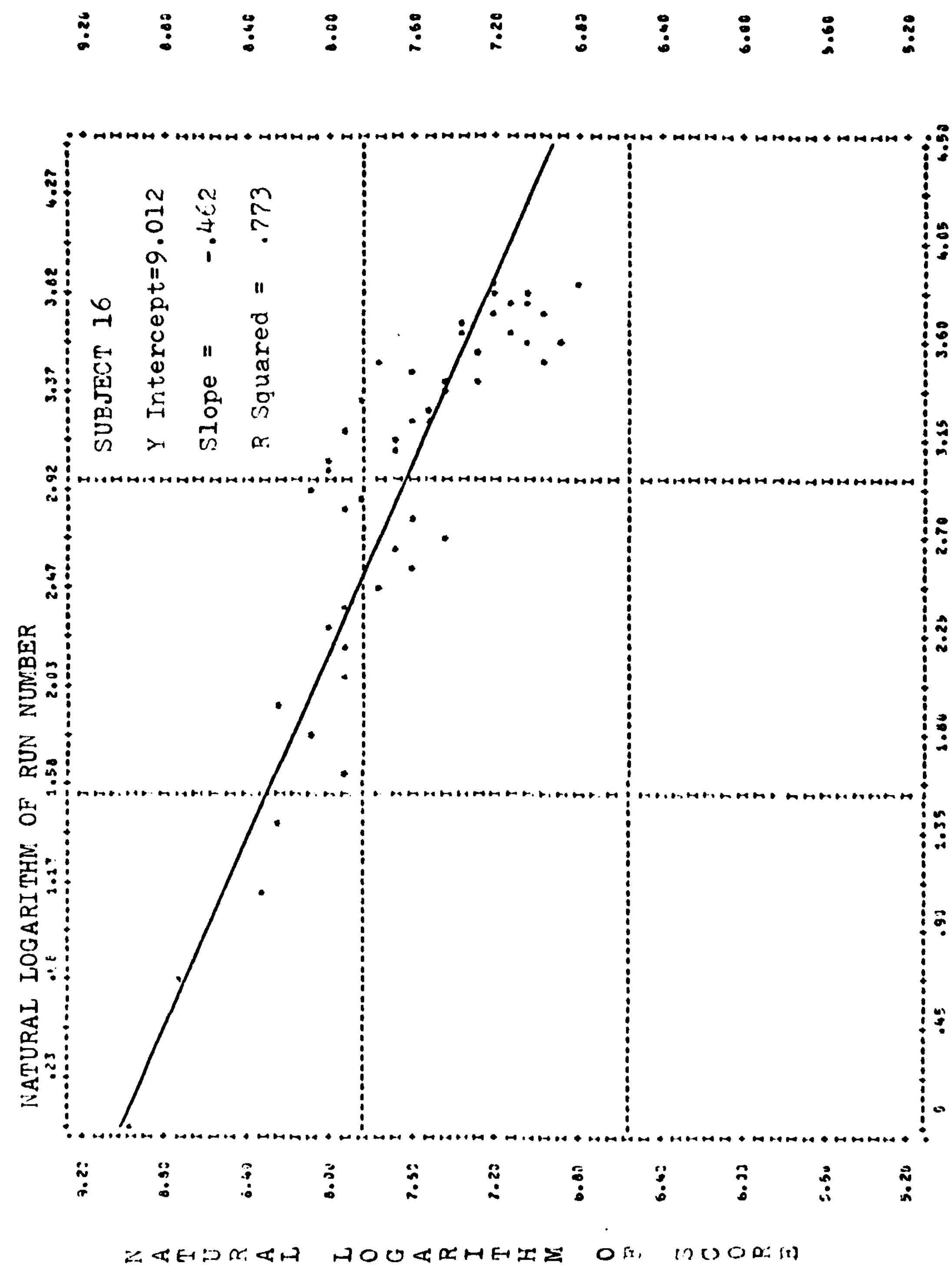


FIGURE 21. LEARNING CURVE, SUBJECT 16

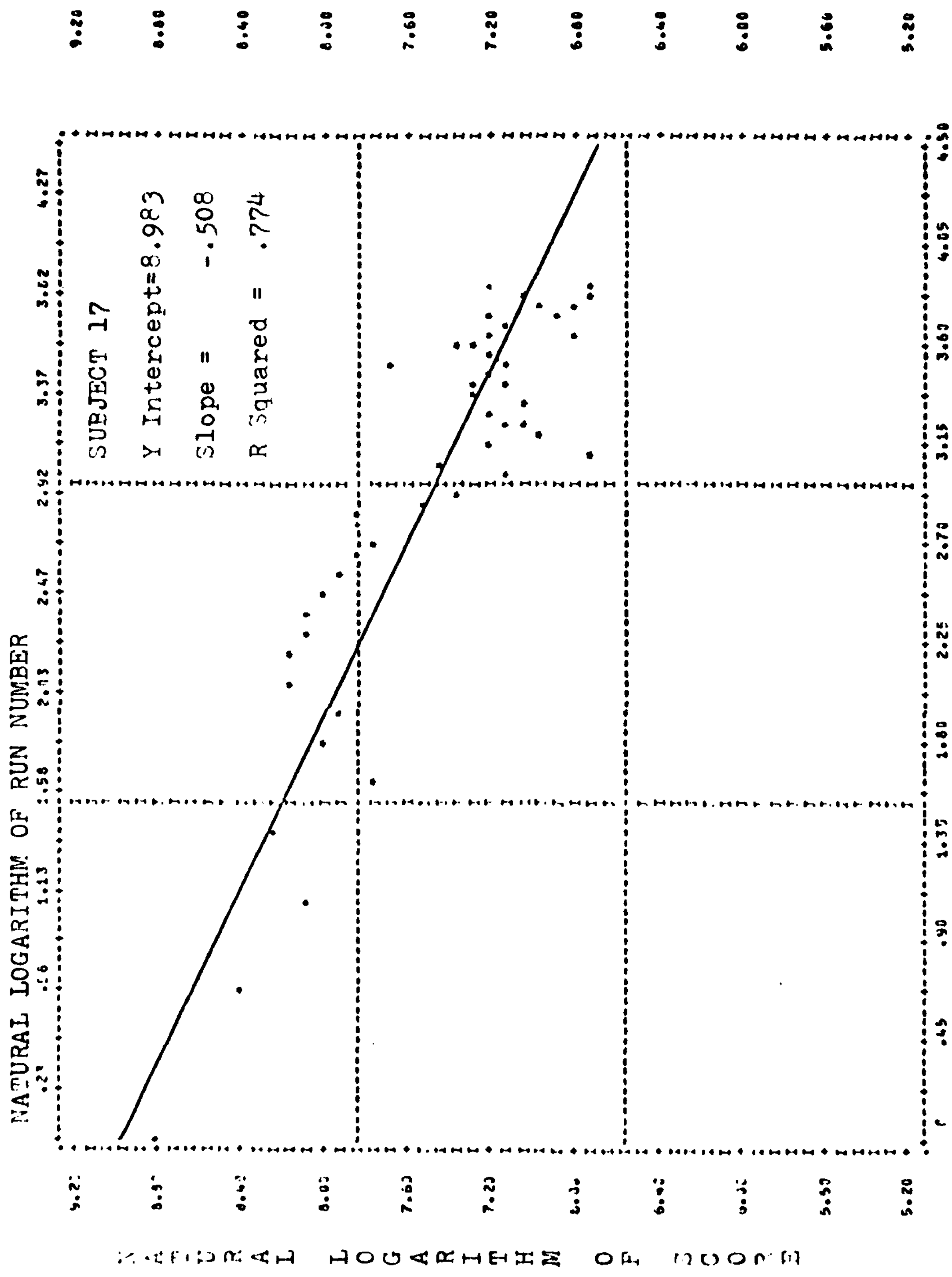


FIGURE 22. LEARNING CURVE, SUBJECT 17

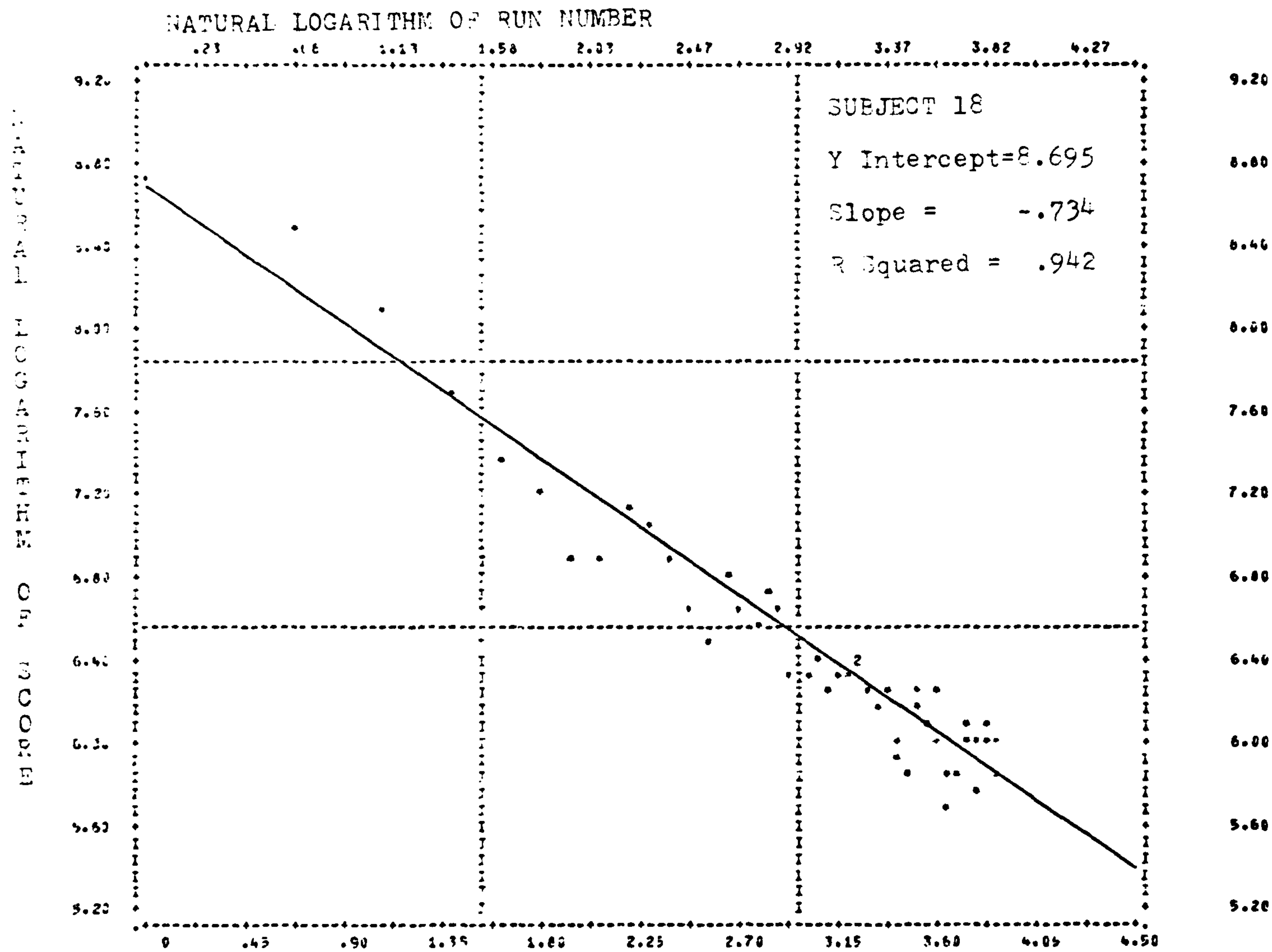


FIGURE 23. LEARNING CURVE, SUBJECT 18

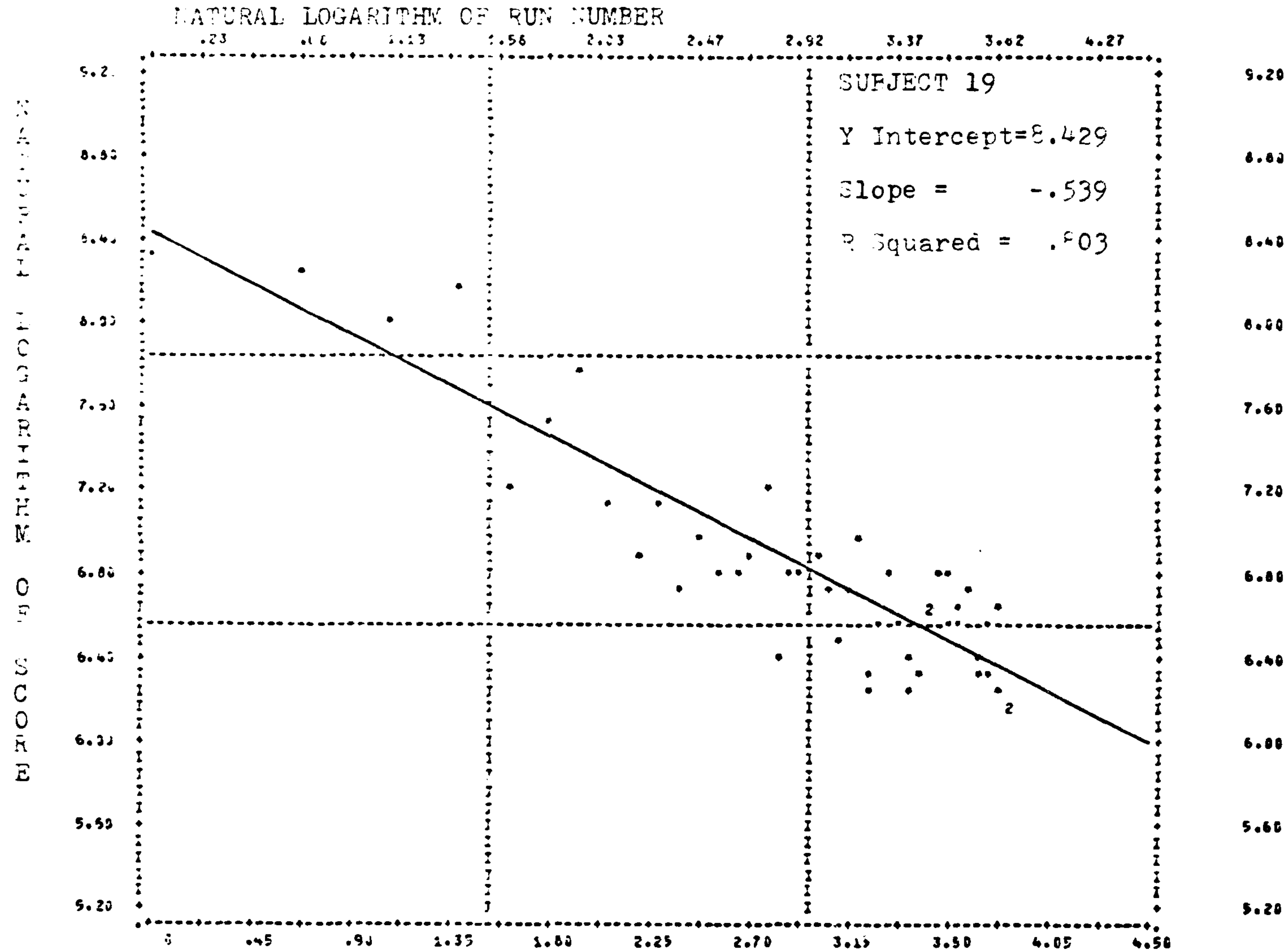


FIGURE 24. LEARNING CURVE, SUBJECT 19

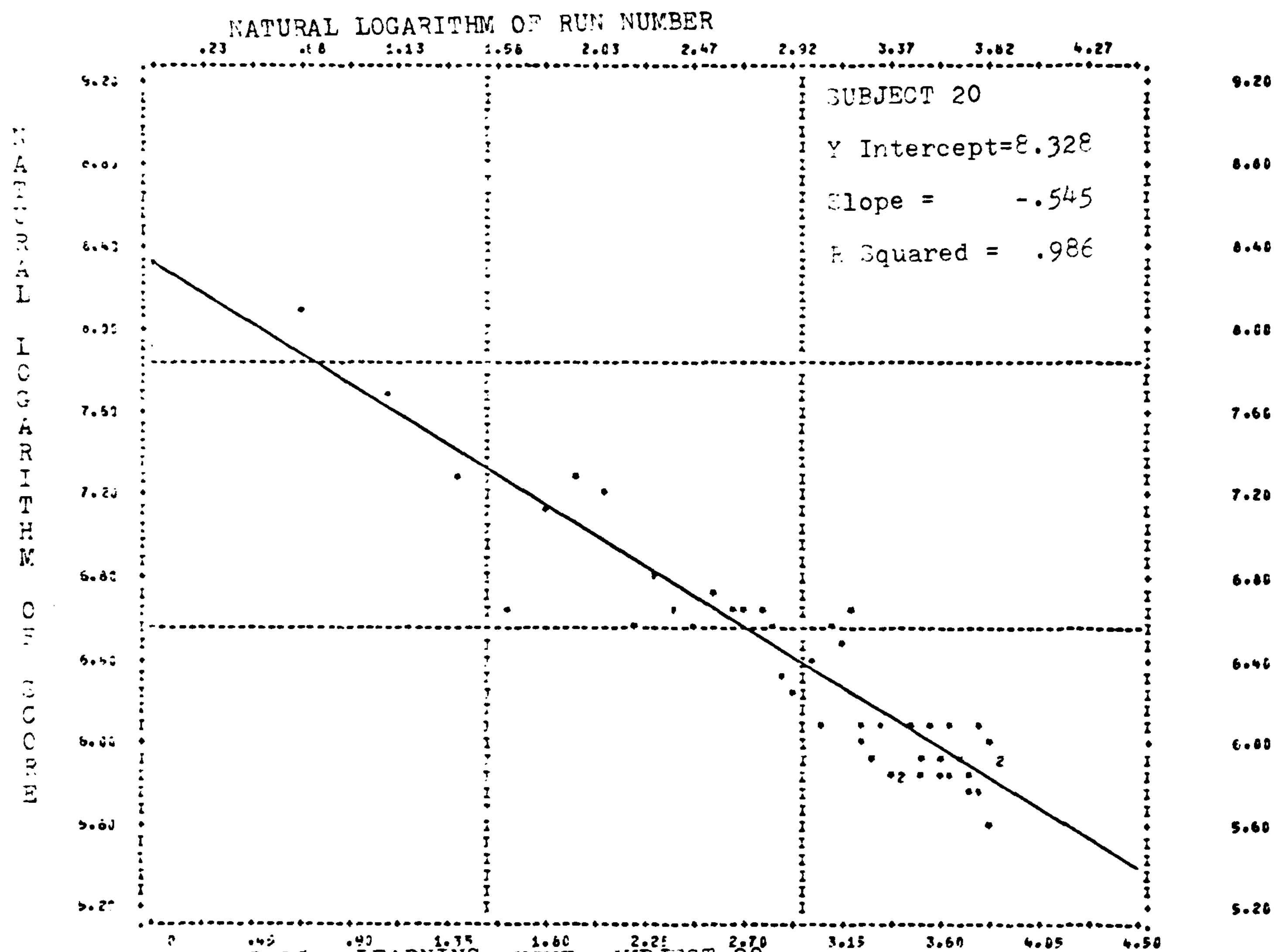


FIGURE 25. LEARNING CURVE, SUBJECT 20

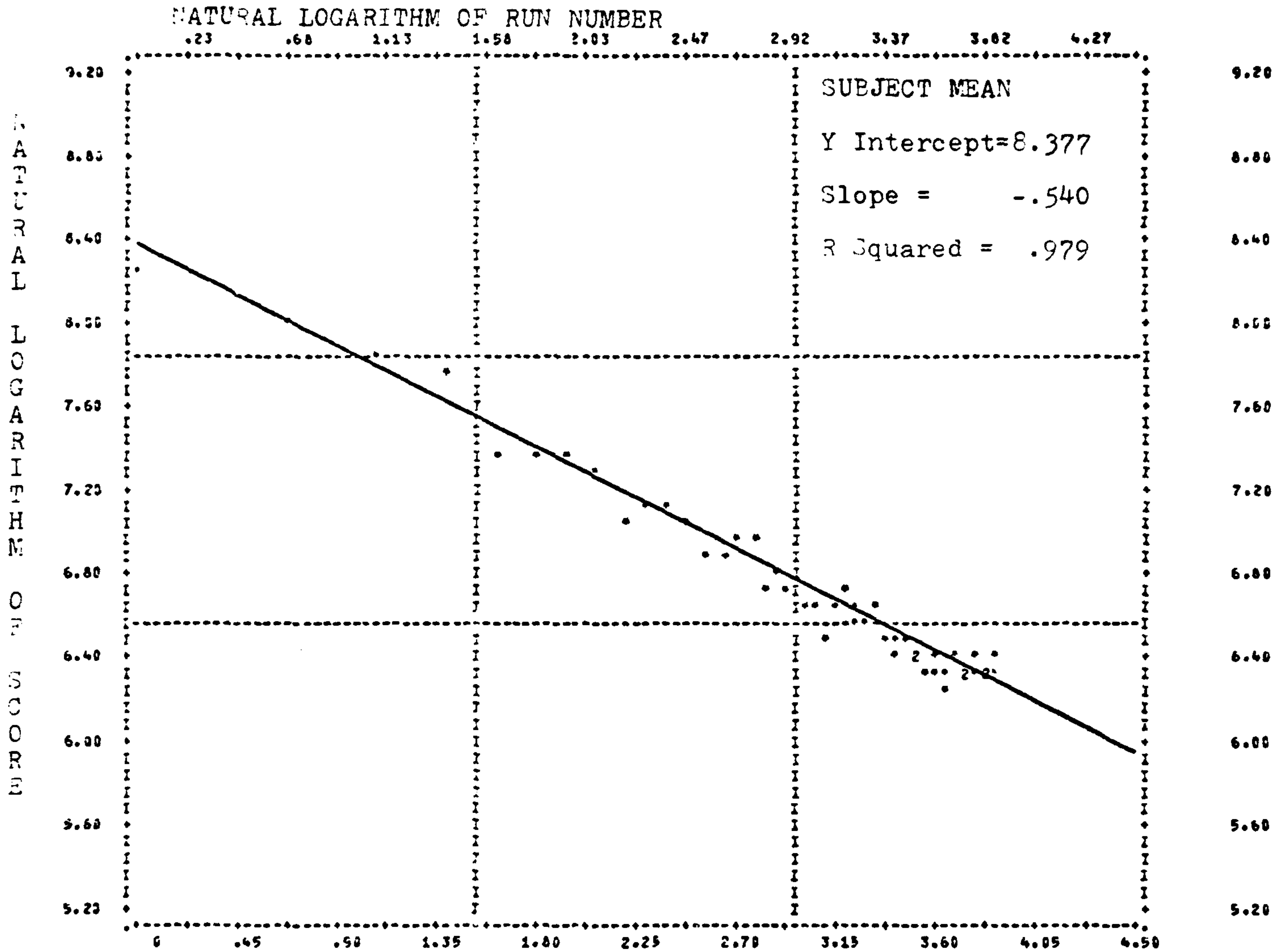


FIGURE 26. LEARNING CURVE, 20-SUBJECT AVERAGE

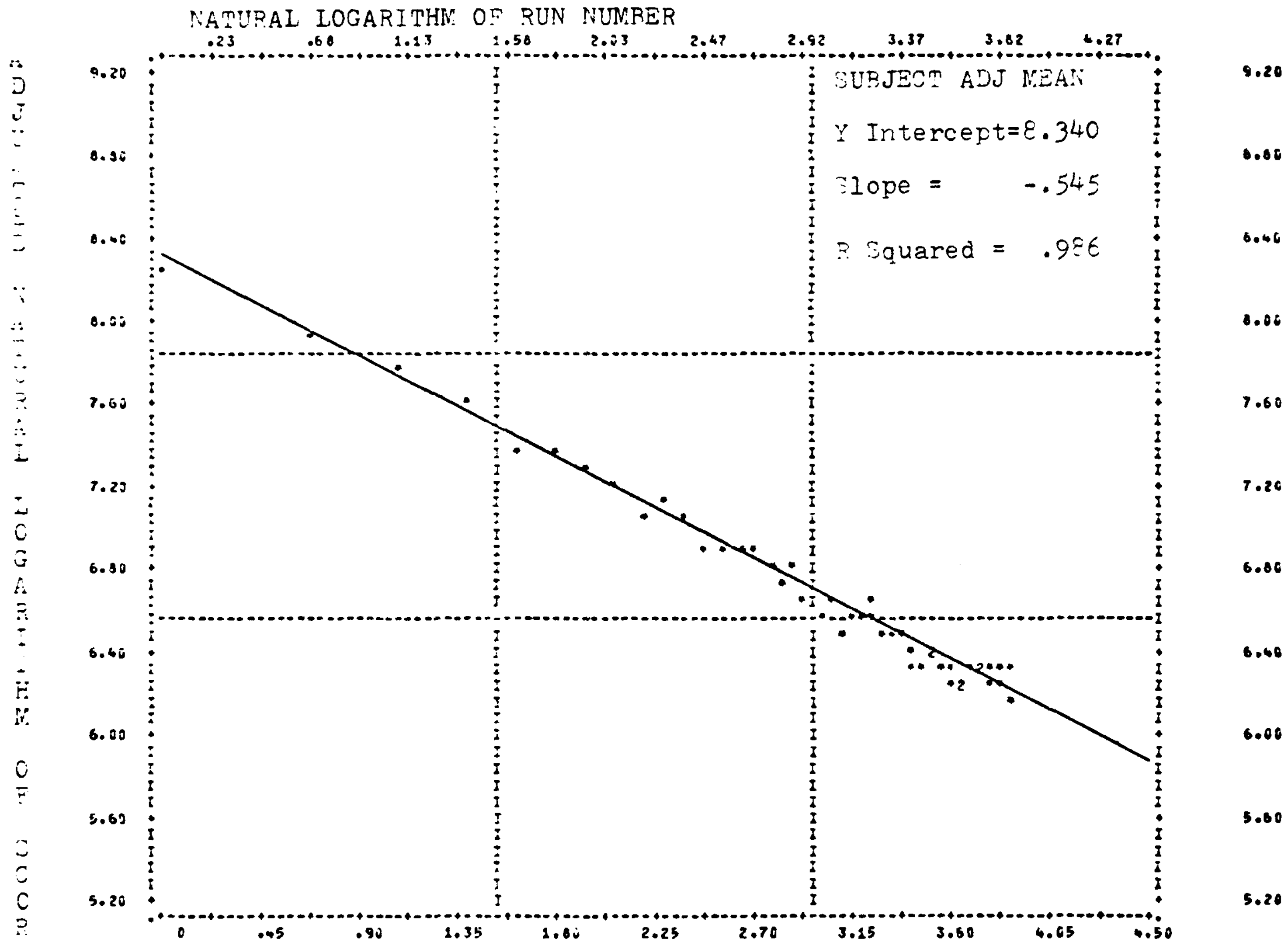


FIGURE 27. LEARNING CURVE, 20-SUBJECT AVERAGE ADJUSTED FOR FATIGUE

VITA

Mark Charles Kipperman was born on 29 June 1947 in Trenton, New Jersey. He graduated from high school in Coronado, California in 1964. He attended Harvey Mudd College, Southwestern College, and San Diego State University, receiving a Bachelor of Arts degree in mathematics from the latter in 1968. In 1969 he was commissioned in the USAF through the ROTC program at San Diego State. He served for two years as an electronics systems officer at La Junta, Colorado, before being assigned to Mather AFB, where he received his navigator wings in October 1972. Subsequent assignments were to Dover AFB as a C-5 navigator and air operations staff officer, and to Hurlburt Field as an AC-130H fire control officer. He entered the Air Force Institute of Technology in August 1978. He and his wife, the former Mary Brigid McAteer, have two daughters, Elizabeth and Sarah.

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